POLITICAL ECOLOGY APPROACHES

TO DEVELOP WILDLIFE LOSS MITIGATION STRATEGIES:

A CASE STUDY OF MITIGATION STRATEGIES FOR

URBAN AND REGIONAL PLANNING TO ADDRESS

WILDLIFE VEHICLE COLLISIONS ON EXISTING ROADS

by

Xue Zhang

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy and Environmental Policy

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ABSTRACT

Road networks play a significant role in shaping the ecological environment. Many roads were built before the rise and spread of ecological preservation through society. Some ill-considered road projects act as barriers to fauna movement. WVCs occur when animals attempt to cross roads to reach different habitat patches. Many animals in human-dominated landscapes are exposed to a high risk of WVC. However, despite high occurrence rates, WVC mitigation measures have not been implemented widely. There seems to be a consensus of opinion that in most cases WVCs do not demand immediate action because they do not impose significant impacts on the total populations of species, and a species often found killed on roads may simply reflect the presence of large thriving populations. There is a long-standing method to identify the alarm threshold for WVCs—the proportion rather than the total number of a population killed in WVCs is used as an indicator. WVCs that involve medium- and small-size animals get even less attention because they do not lead to high economic and human health costs. This opinion discourages efforts toward WVC mitigation.

This dissertation explores solutions for WVC by focusing on the underlying ideology of urban planning. The prevailing anthropocentric ideology is challenged by

deep ecology and is proposed as a complementary approach to conventional economic analyses used by urban planners. This complementary approach addresses the deficiency of current decision-making processes in urban planning. Deep ecology presents a new scenario to develop WVC mitigation strategy.

The premise of this research is that planning departments could and should play leading roles in mitigating WVCs. Every stage of WVC mitigation—planning, designing, constructing, and maintaining—requires interdisciplinary collaboration. Political ecology encourages an integration of politics and environmental science. Urban development has a 'co-produced' social and ecological change with a distinctive distribution of effects on and in the natural and social worlds (Byrne *et al.*, 2002). Planners can be especially creative in combining procedural and substantive skills from once-separated disciplines and, thus, become leaders in the battle against WVCs. In addition, only the planning department through its regulatory powers, has the ability to enact standard rules to ensure that the benefits of non-human life will not be ignored.

Illuminated by *deep ecology*, this dissertation offers a new perspective to examine WVCs—all life forms should be examined in terms of what is ethically right instead of what is socio-economically manageable. Deep ecologists have been characterized as 'questing for ways to liberate and cultivate the ecological consciousness' (Devall, 2015, p. 317). They criticize the dominant anthropocentric paradigm and suggest alternative visions of man-in-nature. This research offers initial efforts in this direction. Theoretically deep ecology maintains that non-human beings are equal in fundamental worth in biosphere. Applied in urban planning, I propose to deploy deep ecology not to advocate an absolute egalitarianism; instead, I suggest its use to offer a strong motivation to develop a WVC mitigation strategy—to preserve life and reduce suffering rather than maintain the local ecosystem or reduce economic losses. At least for the purpose of this dissertation, this is the interpretation I have used to characterize deep ecology in practice.

Urban planning has a long tradition to serve human beings. Ecologies are normalized as the fate of urban development—a necessity regardless of its implications for justice (Byrne *et al.*, 2002). This research questions this strand of urban policy research, and examines value-based biases in the current paradigm of urban planning research. Through introducing deep ecology to urban planning, this dissertation suggests that urban planning research should spur a paradigm shift from anthropocentrism to eco-centrism. The new paradigm calls for planners to be more respectful of the intrinsic value of life, and to pay more attention to non-human species. The motivation to mitigate WVCs should be not only to ensure human safety but also to save animal lives. It is necessary to understand that humans and wildlife share a common need to move. Wildlife issues should be considered during every stage of road planning to improve the ecological outcome of a road.

Under the new paradigm, this dissertation develops a WVC mitigation framework. The framework uses ecological information to develop effective local WVC mitigation measures and describes how to implement them on local existing roads. The ecological information includes knowledge about the following: a) Species' crossing behaviors. Knowledge of whether animals would avoid roads, how they choose crossing locations, frequency of crossings, behavioral mechanisms in response to approaching vehicles, and numbers of documented WVCs forms the premise for the deployment of mitigation measures. b) Typical species behavior and habitat characteristics. These information sources predict animals' reactions around roads and help us to choose appropriate mitigation measures. Only with respect for life and profound ecological understandings will we be able to design sufficient and effective mitigation measures to fight WVCs on existing roads.

As an application of the framework, this dissertation develops detailed species-specific mitigation strategies for four frequent WVC victim species—European badger, eastern gray squirrel, house sparrow, and northern leopard frog. All the four species are frequent WVC victims, but due to their small body sizes, as well as their population abundance, they have received little attention for WVC mitigation. They are still crossing roads without any protection. The strategies developed under the new paradigm contain detailed information on preparation, development, and implementation.

Few forces have been more influential in modifying the earth than transportation.

----Ullman, 1956

Humanity is but a part of the fabric of life — dependent on the whole fabric for our very existence. As the most highly developed tool-using animal, we must recognize that the unknown evolutionary destinies of other life forms are to be respected, and act as gentle steward of the earth's community of being.

---- Gary Snyder "Four Changes", 1970

Life must ultimately be what compels us to change, if anything is going to.

----Foster, 2008

Chapter 1

INTRODUCTION

This chapter provides background information about the rationale for and significance of the research topic.

1.1 Background

Roadways are a common spatial element everywhere that humans have settled. Many countries have given one or two percent of their land to these linear infrastructures (Forman, 1998; ver der Ree *et al.*, 2009). To carry increasing traffic volume, existing roadways are straightened and widened and new ones are constructed. Developing countries are expanding roadway networks into remote areas to connect them physically with cities. The length of roads in China today is 45 times what it was 60 years ago (News.cn, 2015). By 1995, India had only 200 miles of highway, and no expressways. Today the country has the second largest road network in the world, though it is notorious for its poor quality (National Highways Authority of India [NHAI], 1998, 2015). Roadway expansion is much slower in developed countries, however, the number of motor vehicles is also increasing rapidly. Great Britain has increased its road length by only 2.4% over 20 years, but its motor vehicle traffic increased by 18% in same period (Department for Transport, 2014, 2015).

Between 1997 and 2007, the length of roads in the U.S. increased by only 2%; however, the number of miles traveled per vehicle increased by 18.7% and the number of miles driven per capita doubled over the last generation (Barthelmess and Brooks, 2010; Wheeler and Beatley, 2009). It is expected that over the next 20 years, more cars will be built than in the auto industry's entire 110-year history (The World Bank, 2015). With motorization and urbanization on the rise, the expansion of roadways and increased traffic volume are expected—both of which will add to environmental burdens.

Roadways are one of the most visible manifestations of social, economic, and political decisions that lead to landscape change; they also appear to have the upper hand over other anthropogenic causes in ecological disturbance (Coffin, 2007). A suite of ecological impacts by roadways on species, soil, and water have been presented by researchers. Wildlife-vehicle collision (WVC) is frequently mentioned due in part to the high risk posed to animals that attempt to cross roadways, which increases species' susceptibility to population decline, or even extirpation. Almost all published papers reviewing the ecological effects of roads note the importance of WVC (*e.g.*, Fey *et al*., 2015).

Roadways also can create habitat for many plants and animals. Some small mammals and insects use roads as a linear habitat to move and disperse, while some birds use roadside vegetation for breeding, foraging, and resting (Coffin, 2007; Erritzoe *et al*., 2003; Taylor, 2007). Generally, roadways appear to be relatively unimportant as conduits of fauna movement, and are inhospitable and even lethal for wildlife population. In addition to producing dangerous wildlife corridors, roadways slice fragments habitat by dividing it into smaller, spatially disjointed landscape units (Forman, 1998; Theobald *et al.*, 1997).

Habitat integration is crucial for biological dispersal and the basic mechanism of dispersal is movement from one place to another. Animals addressed in this research are capable of locomotion and movement is essential to the fitness of an individual and to the stability of a local ecosystem. Roadways cut through animal home ranges prevent animals from reaching other habitat patches to find food, mate, or avoid predators; reducing species viability; and even leading to local population extinction. Furthermore, fragmentation reduces the probability of recolonization in the event that a species disappears from a given patch of habitat (Theobald *et al.*, 1997).

Roadways act as barriers to fauna movement either through mortality from WVC during crossing attempts or through behavioral avoidance (Fey *et al*., 2015). The different responses of species to roadways depend on their specific behavioral characteristics. If individuals avoid approaching or crossing roads, their movements can potentially be directed away from roads; some may try to cross to disperse to different habitat patches, which exposes them to a high risk of WVC. WVC is among the major causes of death for many animals in human-dominated landscapes (*e.g*., Forman and Alexander, 1998; Langevelde and Jaarsma, 2009; Trombulak and Frissell, 2000). It has become disturbingly familiar—even acceptable—for drivers seeing wildlife flattened on the road or lying battered on the shoulder. The natural defense mechanisms of many animals are useless against this artificial danger: hedgehogs roll up into a ball and rely on their spines for protection; deer and rabbits freeze; turtles retreat into their shells. These self-defense behaviors have been developed over centuries to counter their natural predators. Vehicles are another matter—they move at a speed not possible for most things in nature, and often animals have no concept of the speed at 60 mph (Grant, 2004). Natural defensive behaviors cannot resist the crushing force of a vehicle.

Even if an animal is only hurt, it is likely to die later from the injury or from shock (Taylor, 2007). According to the Humane Society of the United States (2012), over one million animals—birds, reptiles, mammals, and amphibians—are killed every day on roads of the country, the equivalent of a collision every 26 seconds. This number has grown in recent years[1] (California Roadkill Observation System, 2013; Gaskill, 2013; Lister, 2012). Germany has over a million WVCs every year (Koch, 2013). Victims in WVCs not only include the animals killed, but also those litters or juveniles that become orphans and subsequently die. It is estimated that at least 10% of all litters in the Netherlands are lost because lactating females are killed on roads (Dekker and Bekker, 2010).

As a governmental agency, the planning department often impacts natural ecosystem in urban development, but they also have unique opportunities to

[1] According to Barthelmess and Brooks (2010), because of the time lag between mortality events and the opportunity to detect them, especially for small-sized carcasses that remain on the road for less time, road mortality may be underestimated in most surveys. For example, only 7% to 67% of the total road victims are found even when patrolling the road by foot once every 24 hours (Barthelmess and Brooks, 2010; Hels and Buchwald, 2001;). Dekker and Bekker (2010) also mention that the number of victims may underestimate the true figure because “not all animals that are found are reported, and not all animals hit by cars are found” (p. 85).

compensate loss through mitigation strategies (Thorne *et al.*, 2009). Planners can be especially creative in combining the procedural and substantive skills from once-separated disciplines and, thus, become central players in the battle against WVC. In addition, only the planning department, through its regulatory powers, has the ability to enact standard rules to ensure that the benefits of non-human life will not be ignored (Ernst, 2009).

The premise of this research is that the planning department can be an important driving force behind increased WVCs. The ideal role of a planning department is to address wildlife protection with dual strategies: 1) to manage and resolve conflict—whether the planner should be a neutral moderator, or a wildlife advocate is a long-standing debate, and this research will not address it; and 2) to promote an effective solution. Planners have substantive knowledge of how cities, roads, economies, and ecologies interact (Campbell, 1996), so they can put forth specific, far-reaching strategies that promote creative technical, architectural, and institutional solutions. For mitigating WVC, those approaches most open to planners' contributions involve land use, crossing infrastructure design. As with other environmental problems, government intervention is essential for finding a solution to WVC. This position is based less in ideology than in the realization that government intervention is the only viable option to bring about significant change (Ernst, 2009).

A common analytical approach to setting environmental standards requires some consideration of costs and benefits, this methodology has some intrinsic flaw to discourage the development of an effective mitigation strategy.

1.1.1 Beyond the economic valuation

The Good Road Guide, the United Kingdom Highways Agency's environmental design guide for inter-urban roads (Department for Transportation, 1996), mentioned implementation of badger WVC mitigation measures. The guide noted that the exclusive fencing intended to guide badgers to crossing tunnels is not effective and is an unnecessary expense. Instead, the guide suggests that some vegetation around the tunnel entrance to make it attractive to badgers to use was all that needs to be done. This advice is ill-conceived and not based on the available information. In most situations badgers are reluctant to use under-road tunnels and have to be forced to do so at first, making exclusion fences necessary (Royal Society for the Prevention of Cruelty to Animals [RSPCA], 1994).

This is a typical case in WVC mitigation. In most cases Urban Planning department uses economic valuation as a decision aid for environmental policy (Braur, 2003). The decision-making process is not based on the research on the target species' ecological information, but relies heavily on an economic standard which developed on marketing mechanism.

The economic approach ensures an "objective" government process in which those non-human lives remain a low priority. The sacrifice of ecologies for so-called "development" comes to mind here. WVC, especially those that do not induce high economic and human health costs, are imbued with insufficient sense of urgency.

1.1.2 Consideration for the intrinsic value of life

Beyond the linear land roads occupy, the "road effect" permeates adjacent landscapes and ecosystems with primary, or direct, effects, as well as secondary, or indirect, effects. In the United States, as of the early 21st century, there are 6.5 million miles of public roads (Lister, 2012). These roads impact an estimated 15% to 22% of the land mass in the United States (Barthelmess and Brooks, 2010; Bennett, 1991; Forman, 1998; Forman and Alexander, 1998). WVC is frequently mentioned as one of the main road effects, however, there seems to be a consensus that in most cases WVC does not demand immediate action. Most scholars share the opinion that a species often found killed on roads may simply reflect the presence of large thriving populations, and WVC hardly imposes significant impacts on the total population of species (*e.g.* Forman, 1995; Hels and Forest, 2001; Hodson and Snow, 1965). In this researcher's opinion, this point is insufficient to discourage efforts towards reducing WVC. There are three reasons for this position.

First, despite the overall pattern, in some instances WVC can be catastrophic to a species' total population (Bouchard *et al.*, 2009; Forman and Alexander, 1998; Glista *et al.*, 2009; Langevelde and Jaarsma, 2009), especially for species with low-reproductive rates[2]. The evidence for this statement is solid. For example, in the United States the Florida panther (*Felis concolor coryir*) lost 50% of its population in WVCs (Harris and Gallagher, 1989); in Great Britain, 50,000 badgers (*Meles meles*)

[2] If a significant proportion of a population is killed in WVC, and this increased mortality is not compensated by birth and immigration rates, population persistence can be compromised (Jaeger *et al.*, 2005). Those with a huge total population and high reproduction will be relatively insensitive to WVC mortality, the location with declined population can be recolonized rapidly (Forman and Alexander, 1998).

were lost to collisions, which equated to 49% of all adult and post-emergence cub fatalities (Clarke *et al.*,1998); and WVC led to the decline of populations of barn owl (*Tyto alba*) and little owl in Western Europe (*Athene noctua*) (Orlowski, 2008). Harris and Scheck (1991) noted an unpleasant fact that road-related accidents are the primary source of mortality for all of Florida's large, rare, and endangered vertebrates.

Second, WVC leads to high rates of injury, or death, for vehicle occupants. In the following chapters, it becomes clear that an anthropocentric planning approach has significant limitations as to addressing WVC causes high levels of individual and property damage, although human mortality is far less than animal mortality. A staggering US$8 billion is spent every year on recovering WVC-induced damages (Lister, 2012). There were approximately 200,000 WVC-induced traffic accidents in 2012 in Germany, in which 20 people were killed, and 615 were injured, incurring about half a billion euros in insurance losses (Koch, 2013). Losses are increasing because of increasing traffic volume and expanding road networks. Given the consistent increase in WVC-induced damages, it is necessary for federal agencies and state departments of transportation, responsible for everything from planning to engineering roads, to develop an appropriate WVC avoidance strategy.

Third, the intrinsic value of life cannot be measured by economics statistics alone. Incomplete evaluation of wildlife is responsible for decisions in disfavor of WVC. Economic values are derived from individual preferences and are based on an anthropocentric ethic. However, wildlife has its intrinsic value which is not measurable in conventional economic terms, and the loss of life is irreversible

(Brauer, 2003). Aldo Leopold, the father of modern environmental philosophy, appealed for natural resources to be examined in terms of what is ethically right instead of what is solely economically right—"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community" (Leopold, 1949. p. 224-25). From this perspective, the absolute number of lives lost rather than the percentage of the local population (obtained by dividing the number of victims by population size in census years) should be attended to. For example, 159,000 mammals and 653,000 birds are killed in WVCs annually in the Netherlands (Bennett, 1991); seven million birds in Bulgaria (Forman, 1995); and five million frogs and reptiles in Australia (Forman and Alexander, 1998). In this researcher's opinion, the major factor justifying implementation of WVC-mitigation measures should be an absolute number of victims rather than a mortality rate. Beyond showing its ecological value, an animal should be treated as a life first.

All existing life forms are unique components of the world and essential contributors to the diversity of nature. This viewpoint is embodied by an ecosophy—deep ecology—which is an important theory illuminating this research. Deep ecology is famous for its opposition to industrialization (Kvaloy, 1993); however, the characteristic principle applied in this research is biospherical egalitarianism (Devall, 980; Naess, 1973; Naess, 1993). More than a sentiment of affection for wild creatures, this principle involves a deep-seated respect for ways and forms of life. Applied in this particular issue, the motivation to mitigate WVC is first to preserve life rather than maintain the local ecosystem or reduce economic losses.

1.2 An Ecocentric Research Approach

WVC is the cumulative result of three factors: (1) road scheme, including roadside vegetation cover, width of the road segment, traffic volume, speed limit, *etc*; (2) adjacent landscape characteristics, including the location of roads, the surrounding terrain, density of the road network, and so on; (3) species' behavioral and physiological characteristics. We should rethink the road design and plan based on the emerging principles on road ecology. Due to the existing knowledge gap concerning WVC mitigation, the objective of this research is to evaluate all three factors, with emphasis on the third. To better avoid WVC, it is necessary to understand that humans and wildlife share a common need to move, and to rethink the human-dominated traffic model. Animal distribution and movement patterns should be a part of the local context in WVC mitigation strategy development.

Species' crossing behaviors, especially their performance and reaction to roads supply essential information for implementation and management of WVC mitigation measures, and improve planning for future roads (Finder *et al.*, 1999; Mazerolle *et al*., 2005). The performance and reaction of wildlife populations that inhabit the surrounding landscapes determine the location and frequency of WVCs. Inter-specific sensitivity to human disturbance dictates whether animals will access roadways. For instance, chipmunks (*Tamias striatus*) and white-footed mice (*Peromyscus leucopus*) appear to avoid roads consistently (van der Ree, 2010). Some species do not show a strong awareness of roads. For example, the squirrel glider (*Petaurus norfolcensis*), which has high disturbance-tolerance for noise, pollution, and light may cross roads. White-tailed deer (*Odocoileus virginiana*) often feed on grassy road shoulders and, as a result, is frequently hit by vehicles (Oxley *et al.*, 1974). Knowledge of whether the animals would avoid roads, how they choose crossing locations, frequency of crossings, behavioral mechanisms in response to approaching vehicles, and numbers of documented WVCs forms the premise for the deployment of mitigation measures.

In addition to crossing behaviors, ethology[3] also plays a role. Typical species behavior and habitat characteristics may be used to predict reactions to roads and to choose appropriate mitigation measures. For example, arboreal mammals such as greater gliders (*Petauroides volans*) use gliding locomotion to move between trees, and depend on tree cover for movement across their home ranges. As a result, wildlife crossing structures built over a road as a WVC mitigation measure may not facilitate their movement, whereas rope bridges that link tree canopies across roads might be more effective (Taylor and Goldingay, 2009). Animals that are wide-ranging or slow-moving, and those who seasonally cross roads to reach mating or nesting sites, are more likely to participate in WVCs. It is important to consider individual species' behavioral characteristics. Seasonality of animal movements and dispersal helps planners to make informed choices. Therefore, it is critical to integrate scientific research findings and field work in ethology with WVC-avoidance strategy development.

[3] Ethology is "the scientific and objective study of animal behavior, usually with a focus on behavior under natural conditions. It is a combination of laboratory and field science, with strong ties to other disciplines (e.g., neuroanatomy, ecology, evolution)". (Merriam-Webster. Retrieved on Oct. 4th, 2016).

Another road effect noteworthy here is wildlife behavioral modification due to the roadway interruption. Such changes likely occur over a short term (some generations) (Baguette and van Dyck, 2007). For many species, the behavioral modification is very often the first response to human-altered conditions. Such modifications can potentially improve an organism's prospects of surviving when they are confronting roads; however, not all behavioral modification are beneficial (Wong and Candolin, 2015). For example, birds are known to change their calls in response to the disturbance of road-related noise (Jaeger *et al.*, 2005); black bears (*Ursus americanus*) learn to avoid WVC during maturation; and amur tigers (*Panthera tigris altaica*) roam more often near high-WVC hotspots to eat carrion (Coffin, 2007). The ecological effects of behavioral change are probably greater than those of WVC (Forman and Alexander, 1998). The target species' behavioral modification should be considered during the development of WVC mitigation strategy.

1.3 Fill the Gap

1.3.1 Spur a paradigm shift to save lives

'Political ecology' emerges in the 1960s and 1970s during the growing concern about human impacts on the biophysical environment (see Russett, 1967; Wolf, 1972; Miller, 1978; Cockburn and Ridgeway, 1979). It refers to the social and political conditions surrounding the causes, experiences, and management of environmental problems (Forsyth, 2003). Scientific understanding, especially ecological understanding is an important tool for dealing with environmental problems. In the framework of political ecology, ‘ecology’ is therefore inherently ‘political’ (Forsyth, 2003). As Paul Sears states, “by its very nature, ecology affords a continuing critique of man’s operations within the ecology” (Sears, 1964. p. 11-12). Somehow that knowledge must be integrated with political insight, and tempered with respect for the biosphere (Ludwig *et al*., 2001).

Political ecology, on the other hand, emphasizes that natural resources have intrinsic value. It takes natural resources as “commons” rather than “commodities” (Byrne *et al.,* 2006). Environmental conflicts are often presented as technical debates among rival policy advocates, but the source of environmental conflicts run far deeper— a value-based debate lies at the heart of environmental conflicts (Ernst, 2009). Layzer (2006) explains it this way:

> *Environmental policy disputes are, at heart, contests over values. To the casual observer, these conflicts may appear to revolve around arcane technical issues, but almost all of them involve a fundamental disagreement over how human beings ought to interact with the natural world. Even though environmental disputes are grounded in conflicting moral beliefs, the participants in environmental policy contests rarely make value-based arguments. Instead, they define problems in terms of science, economics, and risks associated with environmental issues.* (p.1-2)

To encourage planners to be more active contributors in wildlife conservation, it is imperative to address the value-based bias in the current paradigm of urban planning. A shortcoming of society is that as it strives to sustain its political and economic systems, it often neglects to sustain the ecological system (Campbell, 1996).

Today most wildlife species are greatly influenced by human activities, either directly or indirectly. Their survival is no longer mainly dependent upon their ability to adapt to changing conditions, but is largely determined by man's attitude toward them (Neal, 1986). Individuals from other species cannot speak up for their fair share of resources. The goal in planning is therefore to enact a broader agenda: to seek and sustain the balance point, which may vary from case to case, between human and wildlife.

Planners work for wildlife protection in complicated scenarios. In most situations, this objective is in conflict with others. Planners therefore face significant constraints when pursuing this environmental goal. This conflict is not a superficial one arising simply from personal preference, nor is it merely a conceptual clash among the abstract notions of ecological and planning logic, rather, the source of environmental conflicts typically run deeper. In the future these conflicts will reach the historic core of planning (Campbell, 1996).

Various ideologies or movements have emerged to reinforce the importance of wildlife preservation in urban planning, most of them, including the most famous — sustainability — have not gone deep enough to reach the root of the problem. The shallowness of these environmental ideologies explains why much more need to be done to counter increasing rates of WVC. There is no quick fix, because this shallowness is intrinsic to the methodology of research and problem-solving. It is time to re-examine our methods to ensure they are adequate for these new requirements (Ludwig *et al*., 2001).

The motivation to explore WVC mitigation measures should be not only to ensure human safety but also to save animal lives. WVC mitigation research and practice can be undertaken only with tight restrictions under a human-dominated paradigm. Introducing points of view from philosophies or theories that criticize that paradigm will help to spur a paradigm shift, which is necessary to explore solutions for WVC.

1.3.2 Develop a framework for species-specific WVC mitigation strategy development

Cost-benefit analysis tries to mimic a market scenario by setting an economic standard for measuring the success of environmental projects and programs (Ackerman and Heinzerling, 2002). Even without formal cost-benefit techniques, development of environmental regulations has almost always involved consideration of economic costs. An intrinsic flaw of this approach is that the value of natural assets cannot be fully interpreted by the monetary indicators. An incomplete evaluation of nature is responsible for decisions in disfavor of nature conservation (Brauer, 2003).

The objective of this research is to suggest solutions from an urban planning perspective. Planners need better tools to understand regions not just as economic systems, or static inventories of natural resources, but also as wildlife habitats and ecological systems. A political ecology approach requires an interdisciplinary methodology to solve problems. The solution is developed mainly based rather on economic standard analysis, but on the analysis of the ecological information of the victim species in WVC. Bridging the chasms between planning and natural science is essential due to linguistic differences which reflect separate value hierarchies are a major obstacle to common solutions (Campbell, 1996). This research seeks a more politically aware approach to environmental explanation (Forsyth, 2003). Basic biological knowledge of a target species' behaviors supplies a tool for mitigation plan development and helps planners find ways to avert more destructive fall-out for WVC mitigation. As Habermas (1971) noted, the study of nature leads to knowledge of what nature is, and to instruction on how man is to conduct himself in accordance with nature.

Ecological information collected about animals for developing a mitigation strategy falls to the following categories:

- Road-crossing behaviors. These are the animals' reactions (stopping, staying, or crossing) when they interact with roads (Oudejans *et al*., 1996). Accurately understanding animals' crossing abilities and relating these behaviors to road conditions (vehicle time gap, speed limit, road width, etc.) are essential to determining what mitigation measures should be taken and to designing appropriate crossing infrastructures.

  In addition, road crossing occurs at times of normally high activity for a species (Oxley *et al*., 1974). The biology of a specific species influences crossing behavior. Annual activity patterns and life cycle of the target species determines optimal timing for implementation of some temporary or seasonal mitigation measures like traffic calming or temporary exclusion fences.

- Habitat characteristics. Natural habitat has an ordered spatial pattern that emerges from disordered initial conditions through a self-organization process (Rietkerk and van de Koppel, 2008). The structure and dynamics of habitats are complex due to the interactions between species, food-web connections across trophic levels, and landscape modulations induced by biotic-abiotic interactions (Gilad *et al.*, 2004). We can apply habit characteristics in mitigation infrastructure design to create an environment to which the animals have already adapted.
- Species-typical behaviors that possibly affect WVC occurrence. Species-typical behavior patterns, which are so characteristic of a given species that they can be used to help identify that species, can offer important information for the development of WVC mitigation measures[4]. The field of behavioral ecology that has concentrated most explicitly on species-typical behaviors is *ethology*, which originated in Europe in the 1930s as a branch of zoology concerned with animal behavior in the natural environment. Early ethologists, including Konrad Lorenz and Nikolaas Tinbergen (the field's main founders), studied various species of insects, fish, reptiles, and birds and found that many aspects of their behavior are quite predictable. Different individuals of the same species produce identical responses to the same environmental stimuli (Gray, 2002).

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[4] Species-typical behavior can be affected by environment context changes, known as malleability. However, despite such unexpected malleability, the system producing species-typical behaviors normally works adequately for the continuation of the species (Schneider, 2003).

Although ethological studies have rarely considered direct behavioral response to roads, studies of species' fixed action patterns supply valuable reference information for predicting road crossing behaviors. For example, whether animals cross roads depends on their ability to perceive habitat boundaries in natural environment. Avoidance of, or reluctance to, cross the boundary of a suitable habitat likely implies small possibility of road-crossing. This work will take an overview of species' general behavior and collect useful information. Individuals with extreme performances or that undertake exceptional activities are not considered.

- Basic biology of the species. It is necessary to understand the target species' basic biology when developing a mitigation strategy. For example, the occurrence of WVC has obvious seasonal patterns for some species. These patterns are consistent with species phenology. Habitat preference informs the design of artificial crossings for a specific species.
  The compensation rate determines whether WVC affects a local species on the population level. Effects of WVC depend on interactions between species mortality in WVC and reproductive and immigration rates. When mortality cannot be compensated by the reproductive or immigration rate, the local species population decreases. For some species, roads seem to have very little negative, or even positive, effects on population size (Bouchard *et al.*, 2009).

Once a road has been constructed and the ecological corridors have been inappropriately interrupted, the situation cannot be totally redeemed. After all, ecological corridors are not as simple as several crossings that can be restored easily. Therefore, emphasizing ecological considerations in the pre-construction stage of roads is the most efficient way to compensate for negative influences. For existing roads, mitigation is a prominent attempt to compensate for detrimental ecological impacts. In some situations, mitigation measures are able to reduce WVC mortality to an acceptable level. It is crucial to implement the right mitigation measure in the right context, and design it in such a way to maximize its benefits.

This research focuses on negative WVC impacts on existing roads, and how they might be considered in urban planning. Using a framework to develop a mitigation strategy is important, rather than taking unsystematic or piecemeal measures. The specific measures taken will vary among taxa and may also vary among landscapes, but they can share a common framework for step-by-step strategy development. The framework includes the following four elements: 1.Landscape characteristics of the putative WVC hotspots. 2. Effective mitigation measures based on species-specifics. 3. Monitoring and maintenance. 4. A decision-making process to implement WVC mitigation strategies in practice.

This framework focuses on the most relevant components and restrictions in WVC mitigation, but does not consider species- or site-specific details. It is general, simple, and parameter sparse and can be called a conceptual model. This framework only serves as a base for a more detailed strategy, which includes specific details in a local context.

1.3.3 Develop species-specific mitigation strategies for four selected species

WVC mitigation strategy can be developed on multiple scales: landscape scale, state scale, community scale, species scale, *etc.* In some cases, developing a systematic WVC mitigation strategy on landscape scale is more effective. This research is conducted on a species level. It relies on biological knowledge and wildlife's behavioral characteristics to develop WVC mitigation measures. This species-specific research approach highlights the importance of integrating biological knowledge into WVC mitigation. The research offered in the dissertation does not preclude the need for research at other scales; rather, it hopes to offer a compelling case for one scale and hopes that researchers will continue to conduct research at other scales.

Given that we cannot study every species in every situation of interest, it is important to predict and define which species are most likely to come in contact with vehicles so we can tailor specific mitigation measures to them. This dissertation describes four species that are vulnerable to WVC, and develops tactical mitigation measures for each of them.

Mammals, amphibians, reptiles, and birds are all potential WVC victims, but various surveys have indicated that they are victimized at different rates (Ashley and Robinson, 1996; Kioko *et al.*, 2015). Insects are victims too, but little information can be found in the published literature. Among the large pool of candidates, this research selects two mammals, one bird, and one amphibian as target species to develop

species-specific WVC mitigations for them. The four species share the following three characteristics: 1. They are widespread and abundant, with well-established biological knowledge. 2. Identified involvement in WVC based on the published empirical information. 3. Distinctive locomotion patterns, indicating the needs for distinctive mitigation measures.

Table 1.1: The Four Chosen Species

Species	**Frequency found dead in WVC**	**Class**	**Locomotion**	**Foraging time**	**Abundance (Concern on the IUCN's Red List of Threatened Species[5])**
European badger (*Meles meles*)	Frequent	Mammalia	Terrestrial	Nocturnal	Least concern
Eastern gray squirrel (*Sciurus carolinensis*)	Frequent	Mammalia	Arboreal	Diurnal	Least concern
House Sparrow **(***Passer domesticus***)**	Frequent	Aves	Aerial	Diurnal	Least concern
Northern Leopard Frog (*Lithobates pipiens*)	Frequent	Amphibia	Aquatic & Terrestrial	Diurnal	Least concern

A variety of mitigation infrastructures (*e.g.*, tunnels, pipes, underpasses, overpasses, median plantings) have been used to enhance animal movement and to

[5] The International Union for Conservation of Nature and Natural Resources (IUCN, 2016a, b, c, d) Red list of Threatened Species (also known as the IUCN List or Red Data List), founded in 1964, is the world's most comprehensive inventory of the global conservation status of biological species.

lessen WVC occurrence. At present, more than 40 types of mitigation measures have been used aimed at reducing WVC (Huijser *et al.*, 2009). Mitigation infrastructures, especially crossings and exclusionary fences, have been proven as solutions to WVC by practical experience. In some cases they have near-perfect success rates for preventing WVCs (Lister, 2012). However, there have been failures. It is not unusual to hear claims that these expensive features primarily benefit feral species, particularly mammalian predators. Whether the measures are successful depends on fauna movement patterns. To maximize the benefits of these measures, research should be done on the behavioral patterns of target species to identify main determining factors, and then these factors should be considered in combination with traffic safety, economic and other social influences.

There is no single best design model that can be applied to all scenarios; facilities must be designed with site conditions and wildlife dynamics as essential considerations. Different species preferentially use different crossing types, and some species require particular features of the passages: many small mammals do not swim through inundated culverts, but use ledges attached to the inside walls along which they can walk; amphibians use only moist structures. The most successful crossings are those aimed at mitigating WVC for individual species. In this dissertation, a set of computer models of species-specific mitigation infrastructures are developed with the following considerations:

- Choice of the right type of infrastructure. The first step in model development is to define a specific facility type for the target species.

Currently there is a consensus that the proper crossing structures for amphibians are culverts, for arboreal mammals rope bridges with "glider poles" are best, for big mammals overpasses that span the entire width of roads should be built.

- Construction. Certain attributes of the crossing structures influence usage patterns (Woltz *et al*., 2008). Numerous field studies have confirmed that different species favor different dimensions: larger mammals are much more likely to use larger structures; small mammals are more likely to use smaller passages. Poles should high enough for animals to remain above passing vehicles when they glide to a second pole or a tree (Clevenger and Waltho, 2005; MaCall *et al.*, 2010; Mata *et al.*, 2005). By studying the target species' behavioral pattern, average body size, and characteristics of their natural habitat, this dissertation will produce a set of architectural drawings with the detailed dimensions of proposed infrastructure.

In most cases natural materials are believed to be most attractive to facility users. However, other factors such as economy, safety, and sometimes aesthetics also influence material choices. This research does not use these considerations. Construction materials are chosen to wildlife preferences. Light permeability is also an important design consideration. The light influences individuals' use of under-road crossing structures (Woltz *et al*., 2008). A set of construction documents will be produced to describe the construction requirements for a crossing structure, using acceptable industry practices.

Specific designed elements known as "wildlife furniture," integrated with crossing structures, will encourage wildlife use. This furniture is added to make the infrastructure more attractive to the target species. For example, a wet culvert with an artificial pond to attract toads, and overpasses with intentional planted vegetation as foraging resources to attract herbivorous mammals. Appropriate furniture is a significant means to enhance animal use.

The models are developed with AutoCAD and Vectorworks as the main software, and employ a user-centered design (UCD) approach. UCD was initiated in a computer laboratory in the 1980s. It is a both a philosophy and a methodology, which centers on the needs, wants, and limitations of end users of a product. UCD requires designers to not only analyze and foresee how users are likely to use a product, but also to test the validity of their assumptions with regard to routine user behavior in the real world (Abras *et al*., 2004). Users deeply influence how a design takes shape. Most architecture schools have at least one or two courses on architecture and human behavior to develop skills for incorporating behavioral factors in the design process. Such courses come under the labels of *user requirements, behavioral determinants of design,* or *environment-behavior studies in architecture* (Moore, 1979). UCD is the guiding principle for designing the mitigation models in this research. WVC mitigation facility is a special type of infrastructure, the user of it is wildlife. How to meet the target species' needs and how to encourage them to use the facility are priorities of the design.

These species-specific models, which contain detailed information about the specific projects, are developed in an ideal research scenario. They are designed to benefit politically-favored groups through its decisions. These models will need to be modified to respond to local site conditions in practice.

1.4 Outline of Chapters

This dissertation is organized as follows.

Chapter 2: Research Design and Methodology. This chapter describes how the research is carried out, identifies the research phases, and specifies the methodology. The interdisciplinary research questions investigated are presented, along with criteria for selecting data and the outcomes of the research. Potential ethical considerations in carrying out the research are highlighted.

Part A: Research Design

-- Develop a new paradigm

-- Develop a mitigation strategy framework under the presented paradigm

-- Apply the framework

Part B: Methodology

-- Literature Review

-- Data Collection

-- Case Study

-- Computer-aided Model Development

Chapter 3: Literature Review and Conceptual Framework. A thorough and comprehensive review of transportation planning and ethology literature is carried out to characterize the current state of WVC mitigation research, identify blank spaces, and provide a stepping stone for this study. The advantages and disadvantages of the main research approach are discussed, and the potential contribution of this research to the current body of knowledge body is identified. On the basis of this information, a conceptual framework for the dissertation is constructed.

Chapter 4: Paradigm Shift. From the conceptual framework constructed in chapter 3, this chapter moves on to the necessity of triggering a paradigm shift in planning, even though sustainability has been an important issue in development. A new paradigm based on an ecological view is defined. The new paradigm and its constitutive characteristics are used to anticipate possible changes in existing WVC mitigation strategies. The potential ethical controversy embodied in the new paradigm is presented.

Chapter 5: Mitigation Strategy Framework. This chapter develops a WVC mitigation strategy framework guided by the new paradigm principles presented in Chapter 4, and introduces when and how to use biological information when developing effective local WVC mitigation measures on existing local roads. The chapter supplies a general framework and guidance, but not specific details. This framework is an easy way for government agencies, planners, and designers to develop mitigation strategies for local species.

Chapter 6: Species-specific Mitigation Strategies for Four Species. This chapter applies the framework developed in Chapter 5. Four frequent WVC victim species, their behavioral characteristics and appropriate species-specific WVC mitigation measures are identified. The specific mitigation strategies contain detailed information on implementation of mitigation measures. If a crossing facility is presented as an appropriate mitigation measure for a specific species, detailed crossing structure models are developed with the help of computer. Design details of scale, material, shape, wildlife furniture, and so on are all presented.

Chapter 7: Conclusion and Recommendations. The study closes with a thorough overview of the research, draws appropriate conclusions, reiterates the unique research perspective spurred by the paradigm shift, and presents possible future research questions.

Chapter 2

RESEARCH METHODOLOGY AND DESIGN

Linking the traditionally separate intellectual traditions of critical social theory and environmental science is one of the more fruitful aspects of recent interdisciplinary thought (Campbell, 1996). WVC has an interdisciplinary nature, with aspects of urban planning and ecological implications. This research first presents an inquiry into the dominant philosophy in urban planning. This human-dominated philosophy is the root of the problem. Then a new paradigm is set up, which integrates the world views of environmentalists and social theorists. This paradigm presents a new methodology for problem solving. The research develops a WVC strategy using knowledge of species behavior imported from ecology and biology, and provides a framework to guide government agencies in local mitigation strategy development. In this, efficient and rational data collection from related literature is a crucial step. The framework will be constructed based on the information gained from this data collection. To achieve this, a series of methods will be applied, including literature review, data collection and analysis, case study and model construction. The details around application of these methods will be discussed in the third section of this chapter.

2.1 Methodology

This research applies mixed methods. Qualitative methodology presents an inquiry, in which the knowledge claims are made based primarily on constructivist perspectives that come from social and historical construction (Creswell, 2003). This research applies both qualitative and quantitative analysis to investigate biological information for specific species and gather in-depth understandings of behavioral patterns and preferences. Data collection involves gathering numerical and textual information so that the final database represents both qualitative and qualitative information (Creswell, 2003).

2.1.1 Qualitative methodology to set up a new paradigm

Inquiry on the dominant paradigm is based primarily on constructivist perspectives. The qualitative analysis overviews the theories and philosophies that, intentionally or not, contribute to human-dominance. This inquiry is used as a theoretical lens and overarching perspective to collect data with which to construct an alternative. Diverse theories, ideologies and views from philosophy, sociology, and even religion are addressed in chapter 4. These data are collected to advocate against human-centered ideology. The qualitative approach allows room for innovation.

2.1.2 Mixed methods using biological information to develop WVC mitigation measures

The new paradigm includes the pragmatic assumption that an efficient mitigation measure must be designed with UCD principles, which take biological facts, preferences and needs of the species as the most important standards in choosing the right measures. The behavioral patterns of wildlife to a great extent determine the effects of WVC mitigation strategies, so there is a need to examine causes that influence outcomes (Creswell, 2003).

The quantitative analysis overviews basic biological knowledge about and the behavioral patterns of the target species; the qualitative analysis investigates common conservation measures developed for them by government or conservation organization, as well as laws and regulations in place to protect them. This research bases inquiry on the assumption that collecting diverse types of data best provides an understanding of a research problem (Creswell, 2003). The study begins with a broad survey to generalize useful information in chapter 3. Data interpretation is based on the presence of a WVC-mitigation target: to decrease road mortality under the premise that any measures will not deter or block species movement among different habitat patches.

Data are sourced are from literature and media, including public and official documents. Data include numeric information measured by biologists with instruments and textual information resulting from field observation and interpretation. The collected data are streamlined to a definite pattern as the primary basis for interpretation. Interpretation transforms these data to a set of determinant principles for WVC mitigation design—how do the data affect WVC mitigation strategy development? How are the mitigation designs applied to attract the target species to the designed WVC crossing infrastructure and to avoid WVC? Through a framework the data are interpreted and introduced into the process of WVC mitigation strategy development.

2.2 Research Design

2.2.1 Present an inquiry on the dominant philosophy in urban planning

There are multiple reasons for frequent WVCs; however, the ignorance of the planning department is largely responsible (Ernst, 2009). Faced with increasing wildlife mortality in WVCs, planning departments have not done enough. Instead, much of the work is being done by non-governmental organizations, community groups, and local wildlife conservation organizations. The root of this ignorance is a human-centered paradigm that traditionally dominated planning. This paradigm leads to an arrogant optimism about human abilities to dominate and even reprogram nature, imposing the structural methods and theories that do not fit wildlife populations (Lesbarreres and Fahrig, 2002; Forman, 1998). Current WVC mitigation research and practice do not go far enough in advocating for an action agenda to help WVC victims.

A paradigm constructs the framework of concepts, results, and procedures within which subsequent work is structured (Kuhn, 1962). Planning within such a paradigm hardly takes wildlife into consideration in the policymaking process. Thus, unless local WVCs pose serious impacts on humans, few measures are taken to avoid them. In recent years, diverse theories have been presented by scholars to counter this dominant ideology, and have significantly influenced on WVC research. In the practice, however, planning is still influenced by this traditional and rigid framework.

To better solve this problem, it is necessary to think outside the box. Only by doing this, will all life forms be valued and will mitigation attract more resources and attention.

2.2.2 Set up a new paradigm

The subjective mindset is woven into the fabric of science and serves an inevitable component of its structure. Schumpeter (1949) noted that the human mind is scientific knowledge too. The key to spurring a paradigm shift is to change the value system, which guides people to solve a problem.

An efficient solution must be found under a new paradigm which objects to the human-dominated ideology and which does not exclude other life forms from consideration. Planners must realize that each dead animal on the road means there is something wrong with the way they build roads, and that something needs to be fixed (Downer, 2014). Decreasing WVC is not the sole responsibility of biologists or conservationists; the solution cannot be found and implemented without the involvement of planning departments. This research borrows points from a variety of philosophies, ideas, and even religions to spur a paradigm shift. The new paradigm establishes the groundwork for development of a methodology and governs the choice and use of methods.

2.2.3 Develop a solution under this new paradigm

Under the new paradigm, the motivation for mitigating WVC is not only to protect people but also to protect wildlife. It is wildlife on which the mitigation measures should focus. The approach to this problem should be explored based on scientific knowledge of the essence of wildlife from biology. This knowledge forms the base for further demonstration, and finally for construction of the system.

The intent of the new paradigm is to suggest planning that focuses not only on human society but also on wildlife population. The research develops a general framework showing how to apply biological knowledge of species-typical behaviors[6], and habitat characteristics to develop species-specific mitigation measures. The framework consists of step-by-step instructions that can be used directly in practice.

The framework is constructed in a utopia, which does not consider social or economic restrictions. In the real world, financial considerations would dictate that most mitigation strategies be developed to address more than one species.

2.2.4 Apply the solution

In Chapter 6, examples of framework use are presented. The framework developed is species-specific, and is applied to four species that are frequent WVC victims on a local scale. The framework includes a behavioral checklist with predetermined questions. The data collected from the checklist are the main source of information for exploring specific mitigation measures. The prerequisite for implementing mitigation measures is to ensure species' continued mobility among different habitat pitches.

Methods to assess the effectiveness of these measures will be addressed for each species. However, these species-specific mitigation strategies are only presented on a theoretical level.

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[6] The behavior patterns that are so characteristic of a given species of animal that they can be used to help identify that species are called species-typical behavior (Gray, 2001).

Table 2.1 Research Design

Research stage	Activity	Data source	Output	Impact
Inquiry on the dominant paradigm	Human-centered ideology ignores the welfare of the non-human beings	Literature review from sociology, philosophy and urban planning	The necessity to spur a paradigm shift	Encourage planning departments to allocate more attention and resources to WVC mitigation to save lives
Set up a new paradigm	Involve all life forms into consideration in the planning process	Philosophy, environmental revolution theories, and some religious views	Present a new paradigm for problem-solving	
Present the solution	Construct a general mitigation framework that develops species-specific measures based on behavioral characteristics and basic biology	• Biology • Ethology • Strategy development	A general strategy framework for WVC mitigation which supplies a step-by-step instruction	
Apply the solution	Choose four species and develop mitigation strategies for each of them using the framework presented in Chapter 5	WVC mitigation plans and conservation plans for specific species	Detailed mitigation strategies for: • European badger • Eastern gray squirrel • House sparrow • Northern Leopard frog	

2.3 Research Methods

2.3.1 Criteria for information selection

Data collection is the heart of research. The considerable amount of information available today necessitates setting a standard to find reliable, relevant information. The criteria are applied to the following topics:

- Species selection.

The rationale for defining frequent WVC victims has already been given elsewhere; thus, three criteria are used to evaluate whether a species qualifies as a frequent WVC victim are: (1) the total number of individual losses in WVC; (2) the ratio of victims to the local population; and (3) annual human fatalities and property damages.

- Behavior selection.

Species behavior is an approach to WVC reduction in this research. However, not all species behaviors are related to WVC. The behaviors to be studied are road-crossing behavior, including reactions to roads and wildlife crossing structures; and species-typical behavior that potentially affect WVC occurrence and development of WVC mitigation measures.

- WVC countermeasures

To date, various mitigation measures have been implemented, some of which have been evaluated by ecologists through field work; some have been presented in research but not applied in the real world. There is no unified standard for evaluating WVC mitigation measures, so the selection criterion for cases studied in this research are the general principles for research data selection: reliability, accuracy, and evidence.

2.3.2 Sources of data and information

Three major sources of data relating directly to this study exist in the interdisciplinary areas of planning and ecology: 1) Relevant scholarly articles in planning, ecological, zoological, and environmental journals; 2) Project documents and national development plans published by government department that aim to reduce WVC. Most of these documents can be gotten from the website of Department of Transportation; and 3) websites established by environmental organizations, professional associations or research centers to address WVC (like the California Roadkill Observation System, *http://www.wildlifecrossing.net/california/*, or Critter Crossings, *http://www.fhwa.dot.gov/environment/crittercrossings/intro.cfm*), or published, broadcast, or online journalism concerning WVC. Often the sources in the third category describe events instead of gathering accurate data or providing profound insights. However, these data sources have the latest information on implementation of WVC measures and public reactions.

Biology and ethology are well-developed fields, so information collected in these disciplines is trustworthy.

2.3.3 Development of a strategy framework

The next step after data collection is analyzing and using the information. A standard outline is employed to assess the information, and a step-by-step framework for mitigation strategy development is based on the information. This framework is easy and fast to apply in practice for future users.

2.3.4 Expect outcomes

Three outcomes of the research are 1) a new research paradigm that counters human-dominated planning patterns; 2) a framework for WVC mitigation strategy development; and 3) detailed mitigation strategies for the four species that are based on the presented framework.

3D models are designed based on the central principles developed from behavior analyses of the target species in this research. The photorealistic rendered images will be presented through computer modeling and rendering with AutoCAD, Vectorworks, and Photoshop. The 2D and 3D models that created in this research supply a tangible representation of a structure (including wildlife crossings, fencings, and plantings) and a landscape network, clearly showing landscape plans and construction/planting details.

Chapter 3

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

This chapter contains a comprehensive literature review on WVC from urban planning and ecological research communities to understand the current state of knowledge and existing gaps. The main topics of literature review are the ecological effects of roads; species that are most frequently mentioned by researchers; wildlife behaviors that may relate to WVC occurrence and implementation of mitigation measures; road schemes that may influence WVC; and implementation and evaluation of various mitigation measures. This review addresses the necessity of combining the knowledge from urban planning and ecology.

3.1 Literature Review

3.1.1 State of current knowledge

As early as the 1960s, the high wildlife mortality rate in WVCs drew attention from biologists, as evidenced by a number of research papers published in scientific journals and edited volumes. For example, Hodson and Snow (1965) estimated that 13% of the English population of house sparrows (*Passer domesticus*) died in WVCs very year (Orlowski, 2008). Naess (1973) stated that roads may be the single most destructive element in the process of habitat fragmentation and pose a major threat to many species (Jaeger *et al.*, 2006). Current ecological knowledge about roads clusters around five major topics: (1) roadsides and adjacent strips; (2) road and vehicle effects on populations; (3) water, sediments, chemicals, and streams; (4) road networks; and (5) transportation policy and planning (Forman and Alexander, 1998). WVC fits into the second category but is not a hot topic. Barthelmess and Brooks (2010) stated that only little is known about the impacts of WVCs on wildlife and the majority of current research focuses on ungulates due to high economic and human health costs (van der Ree, 2010). The gaping hole in knowledge on this issue represents a research opportunity.

The environmental issues of transportation systems are of interest to researchers, but are relegated to the margins of the field. In the 20th century, environmental topics drew more attention, but have been addressed on a much larger scale, like the ecological effects of landscape change, habitat fragmentation resulting from urbanization, and the negative effects of deforestation. Although the research on the ecological effects of roads is far from well-developed, there is a consensus that it is an important direction for future research. Coffin (2007) has recommended that transportation geographers should develop robust quantitative methods to model, explain, and predict interactions between roadway networks and the landscape. It is reasonable to believe that the underlying trend is positive.

Ecologist Richard T.T. Forman was the first to address road ecological effects as an interdisciplinary topic. He realized the topic was a “sleeping giant” of conservation ecology (Forman, 1998, p. 207). Forman developed a body of science around road ecological effects and named it *road ecology*. Road ecology is built on the mounting evidence that roads have dramatic effects on the ecosystems they bisect. Road ecology posits that the ecological effects of roads are not only limited to the linear area alongside the road, but also extend >100 m away and impact wetland drainage, stream channelization, salinity of surface water bodies, and so on. Forman mentioned WVC as one of the effects, but did not pay much attention to the topic. He stated that WVC may be a premier mortality source in local spots, but that it hardly influenced population size. Road ecology attempts to quantify ecological effects on the road effect zone and the creatures that inhabit it.

Road ecology is rooted in ecology, geography, engineering, and planning. Forman advocated that population ecologists, stream biologists, foresters, engineers, geographers, wildlife ecologists, conservation biologists, landscape architects, and planners join together to work on solutions. The publication of his book Road Ecology "heralded the consolidation of this endeavor at a new conceptual scale, under the auspices of an interdisciplinary scientific umbrella" (Coffin, 2007).

Ecological principles are increasingly important in environmental transportation policy. Contrasting approaches are highlighted in different countries affected by local contexts and public pressure. In Australia, policies focus on biodiversity conservation, and ecologists commonly work side by side with planners and designers in transportation departments at all levels of government. Dutch policy focuses on roadside vegetation, road kill, animal movement patterns, and nature restoration, which are close to the proposed topic of this dissertation. Research and practice on mitigation systems for animals and water flows is especially ambitious and pioneering in the United States. Environmental activists and scientists work closely with engineers and policy makers at local and national levels; in the United States, environmental transportation policies focus on vehicle pollutants, or engineering solutions for soil erosion and sedimentation; to a great extent, policies ignore biotic road effects, including WVC mitigation (Forman and Alexander, 1998). In 2005, the U.S. government passed the "Safe, Accountable, Flexible, Efficient Transportation Equity Act," recommending that early environmental impact assessments and planning should help guide the development of roads (Thorne *et al.,* 2009).

3.1.1.1 Ecological effects of roads

Roads negatively interrupt abiotic and biotic components of the ecosystem they cross. Ecological effects are addressed from different perspectives in literature. The effects can be systematized into the two general categories of biotic and abiotic, and these are shown it in Table 3.1.

Table 3.1 Road Effects

<table>
<tr><th></th><th>Type</th><th>Effects</th><th>Results</th></tr>
<tr><td rowspan="9">Road Effect</td><td rowspan="6">Biotic</td><td>Degrading habitat quality (pollution, habitat loss, habitat fragmentation, human activity disturbance)</td><td rowspan="6">Reduced wildlife population size; reduced population persistence</td></tr>
<tr><td>Population subdivision</td></tr>
<tr><td>Invasive species introduction</td></tr>
<tr><td>Fauna movement barrier</td></tr>
<tr><td>Resource inaccessibility</td></tr>
<tr><td>WVC</td></tr>
<tr><td rowspan="3">Abiotic</td><td>Hydrologic system disturbance</td><td rowspan="3">Environmental conflict</td></tr>
<tr><td>Sediment erosion</td></tr>
<tr><td>Interruption of deposition dynamics</td></tr>
</table>

These effects are not independent of each other. They are correlated and sometimes compensatory. For example, a species with high avoidance of road noise, road surface, light or cars will choose not to cross. This built-in avoidance lessens WVC mortality but increases the barrier effect, which leads to habitat loss, resource inaccessibility, and population subdivision. Thus, these populations are actually most vulnerable to roads even though they do not have high WVC mortality (Jaeger *et al*., 2005). Some effects are interrelated. For example, both WVC mortality and resource inaccessibility contribute to population subdivision (Ford and Fahrig, 2008; Jaeger *et al.*, 2005).

3.1.1.2 Frequent victim species

There is a consensus that slow-moving animals and urban adapters[7] suffer the most loss of lives from WVCs (Coffin, 2007). Urban adapters have a shorter escape initiation distance when approached by humans or vehicles, thus they are especially susceptible to WVC; body size and diet have influences too. Ford and Fahrig (2007) found that mammals of about 1.06 kg body mass were hit more frequently; Oxley *et al*. (1974) also indicated that small forest mammals and medium-sized mammals are severely affected by WVC. Herbivores are more likely than carnivores to be struck by cars (Ford and Fahrig, 2007); diurnal species are more vulnerable than nocturnal species (Hels and Buchwald, 2001); and species with high vagility are at a disadvantage because they are more likely to encounter roads and incur WVC mortality (Carr and Fahrig, 2001). When a species that frequently encounters roads has a low reproductive rate, population size is easily influenced (Barthelmess and Brooks, 2010). Special attention should be given to species with these characteristics.

[7] There is an analogy between wildlife adaptation to roads and another human-modified landscape—urban areas. Some species are urban adapters, able to develop habitats in urban areas and to have apparent tolerance for humans; others are repelled by the disturbances of urban landscapes.

There is difficulty in comparing published WVC occurrence frequencies across different species because how the rates are calculated lacks standardization. Many studies have documented absolute numbers of animals killed in WVCs (*e.g*., Bouchard *et al.*, 2009; Jaeger *et al*., 2005; Langevelde and Jaarsma, 2009), and some have estimated the proportion of animals killed from a local population (*e.g*., Clarke *et al*., 1998; Huijser and Bergers, 2000; McCall *et al.*, 2010). Calculation methods differ, too. In some research the frequency is calculated based on total victim numbers and the length of road that are surveyed, in other studies the rate is provided by comparing observed victims with the number of local population, and in some studies rates are provided but the survey methods are not described (Barthelmess and Brooks, 2010). In addition, Hels and Buchwald (2001) questioned the accuracy of victim counting in WVCs in most field surveys because the victims that disappear from roads before counting are ignored. As a result of the different calculation methods and related inaccuracies, the most-frequent victim species can be defined only coarsely:

Amphibians and reptiles: Amphibians and reptile species, which move frequently and far through the landscape, are slow and show no obvious road avoidance, therefore they are often become WVC victims (Bouchard *et al.*, 2009; Gibbs, 1998). WVC is the greatest road effect on amphibians, especially on two-lane roads with low to moderate traffic and geographically proximity to ponds and wetlands (Forman and Alexander, 1998).

Mammals: Small mammals including porcupines (*Erithizon dorsatum*), raccoons (*Procyon lotor*), cottontails rabbits (*Sylvilagus floridanus*), striped skinks (*Mephitis mephitis*), and hedgehogs (*Erinaceus europaeus*) frequently come into contact with vehicles. Ungulates including deer (*Odocoileus spp.*), elk (*Cervus elaphus*), and moose (*Alces alces*) are addressed in many studies. Although ungulates are not the most frequent victims of WVCs, literature about them is most abundant because collisions in which they are involved cause the most human fatalities and economic losses. In the United States, these collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion dollars in property damage annually (Huijser *et al.,*2009). Arboreal mammals are also frequent road traversers. They are very clumsy when they are moving on the ground and highly vulnerable to road kill. Some arboreal mammals like red squirrels (*Tamiasciurus hudsonicus*) may spend time on the ground as part of their usual activities and become frequent WVC victims. Contrasting opinions exist about WVC mitigation for the arboreal mammals. Some evidence shows that arboreal mammals avoid roads due to the lack of protective cover over road surfaces (Bouchard et al., 2009), so keeping roads clear from plant cover in WVC hotspots reduces accidents. There is also growing recognition that specific crossing structures are needed to meet the needs of arboreal mammals due to their specific movement patterns (Taylor and Goldingay, 2009). Van der Ree *et al*. (2010) suggested planting trees in the median strip to reduce the gliding distance for squirrel gliders.

Invertebrates: WVC rates for invertebrates are far higher than for vertebrates (Seibert and Conover, 1991; Huijser *et al.*, 2009).

Birds: Low-flying birds are most susceptible to WVC. The house sparrow (*Passer. domesticus*), Eurasian tree sparrow (*Passer montanus*) and barn swallow (*Hirundo rustica*) are noted as frequent species killed in WVC.

Insects: Insects are killed in prodigious numbers, attested to by windshield counts (Forman and Alexander, 1998). However, research on insects has been largely ignored.

3.1.1.3 Roadway schemes affecting WVC occurrence

As mentioned earlier, roadways are not homogeneous features for animals to cross. Some topographic features and road construction variables are considered especially conducive to WVC occurrence (Finder *et al.*, 1999). Several road schemes are addressed frequently in the reviewed literature.

Speed limit: Vehicle speed directly relates to WVC frequency. Birds and small mammals are more susceptible to WVC mortality on high-speed roads, reptiles and small mammals are most frequently killed on slow-speed roads (Forman and Alexander, 1998). Hels and Buchwald (2001) noted the exception that some small animal species, which may remain still under a passing vehicle without getting hurt, do not follow this general trend. Gunther (1995) suggests that when the speed limit is lower than 45 mph, WVC may be reduced significantly.

Limiting vehicle speed is a common mitigation measure. Speed limits can be enforced through road design (curves and width) or condition (smoothness). Posted speed limits, which are commonly used, are acknowledged by Gunter *et al.* (1998) as a measure has “the least amount of influence over vehicle speed” (p. 35).

Traffic volume: For many species, the heavy stream of traffic may be a strong deterrent to crossing roads (Abbott *et al.*, 2012; Orlowski, 2008). According to Forman (2000), roads with lower traffic volume produce a filter effect and incur WVCs, whereas roads with higher traffic volume may produce a barrier effect, which blocks wildlife corridors and subdivides populations. For example, bears cross a highway primarily at night to avoid the daytime traffic peak (Lewis *et al.*, 2011), and bird mortality rates in WVC show clear differences for roads with different traffic volumes (Orlowski, 2008). Traffic volume has little effect on gliding mammals because they rarely come down to the ground (van der Ree *et al.*, 2010). However, statistically significant correlation coefficients between traffic volume and mortality level are lacking for most species. Traffic volume and speed are evaluated in combination in most research (*e.g.*, Forman and Alexander, 1998; Reijnen *et al.*, 1996).

Traffic noise: Traffic noise is a major cause of road avoidance. It also leads to degradation of avian communities near busy roads (Forman, 2000; Forman and Alexander, 1998).

Roadside cover type: mowing regimes and planting designs along roads affect accessibility for some species, especially birds and insects (Coffin, 2007).

Contradictory conclusions have been drawn about the influences of roadside planting cover on bird vehicle collision. Some research has stated that the presence of high hedgerows, trees, and embankments (>3 m) forces birds to fly higher and avoid WVCs (Hodson, 1960; Pons, 2000); Conversely, Orlowski (2008) drew an opposite conclusion from field work study. He concluded that the level of losses of birds is positively correlated with the number of reared lived stock and the length of roadside tree belts and hedgerows because such vegetation encourages birds to nest, breed and rest there, thus, exposing the birds to the danger of WVCs. The discrepancy probably is the consequence of different vegetation structures, planting species, or bird species abundances near roads.

Roadside planting also affects the visibility of a road segment. Woods or gullies immediately adjacent to the road may obstruct the visibility of motorists and/or wildlife, prolong the response time of crossing wildlife, and, in turn, increase WVC occurrences (Finder *et al.*, 1999).

Proximity to natural resources: Natural resources include agricultural land and wild landscapes, but exclude built-up areas. A road described as being near natural resources is adjoining, or close enough to affect some natural ecosystem. Observations suggest that the spatial arrangement of resources including food, water, and shelter around a roadway is a deciding factor in WVC occurrence (Coffin, 2007).

All road lengths in rural areas and 25% of road lengths in urban rears are roughly estimated to be near natural resources (Forman, 2000). Rural roads produce the greatest ecological effects. Rural roads with high speed limits and infrequent traffic have the most WVCs (McLendon, 2012). Finder *et al.* (1999) suggested that public recreational land within a 0.8 km radius of a road segment increased the probability of deer vehicle collisions. Forest roads have the most obvious ecological effects (Forman and Alexander, 1998; Lewis *et al.*, 2011).

Road design and physical quality: Road design, including width, height above grade, and plantings along median strips, determines whether and which species will see it as a corridor or a barrier. Materials and techniques used in construction determine the disturbance effect of road segments.

There are many other factors that influence WVC occurrence at landscape scale, such as landscape patterns in which the road is situated, natural habitat quality, and abundance of wildlife populations around roads. These factors will not be discussed in this work because the focus is on mitigation measures at the local level.

3.1.1.4 Characteristics of the adjacent landscape that affect WVC occurrence

The landscape determines the distribution of resources in the environment, influencing the composition, abundance, and mobility of species, and consequently the seasonal and spatial patterns of WVC (da Rosa and Badger, 2012).

3.1.1.5 Behavioral characteristics that may relate to WVC mitigation measures

Species' behavioral characteristics exhibit specific patterns. Understanding and analyzing these patterns is the targeted approach of this research to explore an effective WVC mitigation strategy. Information on animal behaviors constructs a strong ecological base which allows landscape and transportation planners to locate mitigation facilities, determine management activities, and reduce the potential for WVCs during pre-construction road planning.

Crossing behaviors determine crossing hotspots. Crossing hotspots can be defined based on empirical data of prior WVCs (*e.g.*, Hels and Buchwald, 2001; Lewis *et al.*, 2011), can be predicted by target species' routine behavioral characteristics (*e.g.*, Abbott et al, 2012; Hels and Buchwald, 2001). Frequent crossing points are useful to identify a focus for WVC avoidance management and to locate possible crossing facilities. Theoretically when the resources are distributed on both sides of roads, crossing behavior will be more likely to happen (da Rosa and Badger, 2012).

In addition to crossing behaviors, understanding animals' routine behavioral performance under natural circumstances also provides promise for a detailed and efficient mitigation response. Taking bats as an example, some typical behavioral characteristics may guide a WVC-avoidance plan and appropriate road design.

- When bats commute between their roosting and forging sites, they often fly following linear features, such as hedgerows, waterways, and woodland edges. Also, vertical landscape features may provide a source of food, shelter from wind, and cover from avian predation. Therefore, plantings may be designed to be a linear so they can be used as visual orientation cues bring bats to mitigation facilities or away from collisions.
- A gap as little as 10m may deter a bat from its flight path.
- Bat patterns of low speed and altitude lead to preference for underpasses rather than overpasses. Overpasses are perceived by bats as too open, lacking guiding or sheltering vegetation or structure. Underpasses, particularly along rivers, attract frequent bat activity. This highlights the importance of underpasses as mitigation measures for bats (Abbott et al, 2012).

3.1.1.6 Mitigation measures

Most mitigation measures have been developed for ungulates and large carnivores; few are available for small mammals and birds. Deployed in the right place and established with the proper context, some measures can nearly eliminate WVCs. Mitigation measures currently in use generally fall into two categories: modification of motorist behavior or modification of animal behavior (Glista *et al.*, 2009).

(1) Modification of motorist's behavior

Public awareness programs: Programs have been developed to increase public awareness of WVCs and provide useful information that enables drivers to adjust their driving habits and be safer on the road.

Warning signs for wildlife crossings: Over the last decade, installment of wildlife signage, permanently or seasonally, has been the dominant practice by which planning agencies to mitigate WVC (Knapp and Witte, 2005). If collisions are concentrated at a certain time of year, or at certain spots, warning signage is feasible. Warning signs are relatively cheap (*e.g.*, $500.00 each) and easy to erect (Andrews *et al.*, 2011).

Traffic calming: In the 1970s, traffic calming was proposed to lessen WVC in the Netherlands (Langevelde and Jaarsma, 2009). Traffic calming uses speed-reducing measures such as speed bumps and raised level-crossings, either temporarily or permanently, to reduce vehicle speeds as well as volumes. Traffic calming is proven to reduce WVC mortality dramatically for individual animals. However, effects on total population persistence have not been documented (Langevelde and Jaarsma, 2009; Langevelde *et al.*, 2007). Determining traffic-calming locations is a key step adopting this measure. Langevelde and Jaarsma (2007) suggested that the maximum time for leaving the calmed area to continue on the nearest major road is 3 minutes.

Closure or removal of some roads: Closing road segments in specific seasons can be used to avoid of wildlife crossing rush hours. This measure corresponds to WVC peaks, and is mostly used when traffic calming is not effective.

WVC occurrence for most species differs seasonally, and frequency peaks in the periods of highest animal activity (Barthelmess and Brooks, 2010). In breeding season or mating season, a species' home range may expand cross a roadway that was previously out of their habitat border. For example, porcupines (*Erithizon dorsatum*) experience a high salt drive in spring, causing them to move near roads to consume residual road salt. This behavior leads to a WVC peak in spring for porcupines (Barthelmess and Brooks, 2010). In this case, temporary closure of an involved road segment would be a useful mitigation measure. Other factors may also incur WVC peaks. Permanent closure is needed when bottlenecks apparently cannot be overcome by mitigation (Forman and Alexander, 1998).

Technology: Wildlife reflectors or mirrors, and animal detection systems can be used to prolong drivers' reaction times when vehicles encounter crossing animals.

Technology measures have advantages in implementation, economy, and human resources, and are widely used nowadays, although the effectiveness of such measures is largely unknown (Glista *et al.*, 2009; Romin and Bissonett, 1996).

(2) Modification of animal behavior

Animal behavior is not malleable. However, it is possible to regulate their movement to some extent through deliberate design and management. Crossing structures aim to mitigate WVC impacts by providing safe passage for wildlife across roads (Soanes *et al.*, 2013). This method not only serves to lessen WVCs, but also reconnects landscape fragmented by roads, enhances gene flow and fauna movement, and further reduces the possibility of population subdivision. Crossing structures are acknowledged as the most effective mitigation measure to reduce WVC mortality. Puig *et al.* (2012) posited that if crossing structures occur repeatedly, they can reduce the WVC rate for an entire road. However, crossing structures cannot completely eliminate the barrier effect, especially the target species that are vulnerable to road disturbance (Soanes *et al.*, 2013).

The first purpose-built wildlife passage were placed in Europe in the mid-20th century, and a wide range of crossing facilities have since been integrated in new road planning and existing road upgrades, with clear evidence of use by certain species (*e.g.*, Clevenger and Waltho, 2005; Foster and Humphrey, 1995; Jaeger *et al*., 2006; Yanes *et al*., 1995). Although these measures have proven to be more effective, they are less frequently used than those that work on drivers (Grosman *et al*., 2009). Examples of crossing facilities include:

Overpass: An overpass is a land bridge, rope, or wooden canopy bridge that crosses over a road. When designed and implemented strategically, an overpass can be strong in appearance and function (Taylor and Goldingay, 2009; Lister, 2012). Overpass width can be up to 200 m and these structures are preferred by wide-ranging, large species such as deer, moose, and bear. Until 1998, there have been approximately 6 overpasses in North America and 17 in Europe (Forman and Alexander, 1998). Overpasses improve environmental awareness because they are visible and noteworthy to motorists (Lister, 2012).

Underpass: Tunnels, ecopipes, and underpasses all carry animals under roads. Tunnels are generally 30 cm to 100 cm wide and are designed for amphibians and small mammals; ecopipes, with an average diameter of 40 cm, are for mid-size mammals; and underpasses, which are generally 8 m to 30 m wide and at least 2.5 m high, are for large mammals. Tunnels and ecopipes are less costly to build and are more commonly used by a wide variety of species.

Exclusionary fencing: Fences and barrier walls are always used in conjunction with passages. They help to keep animals off the road, stream fauna movement toward the crossing structures, and prevent animals from accessing roads. Fences and barrier walls have been proven effective in reducing wildlife road mortality. For example, in the Paynes Prairie State Preserve, Florida, these measures reduced wildlife mortality in collisions by 93.5% (Glista *et al.*, 2009).

Inappropriate use, however, may lead to a greater barrier effect on fauna movement. In cases where resources are on both sides of a road, fencing is only beneficial if accompanied by a crossing structure (Jaeger *et al.*, 2006). Fences create an impermeable barrier to wildlife movement, which may aggravate population and habitat fragmentation and also make recolonization after local extinction impossible (Grosman *et al*., 2009; Jaeger *et al.*, 2006).

Unfortunately, the most promising measures often are the least used. For example, many U.S. states used warning signs and public awareness programs to resist increasing WVC, although the effectiveness of such measures was largely unknown to them. Conversely, relatively few U.S. states use wildlife crossings, fences to reduce WVC, even though these measures are proved more effective (Romin and Bissonette, 1996; Gilster *et al*, 2009).Crossing structures are a prominent solution for the WVC problem, though nonfunctioning crossing structures are prevalent (Woltz *et al*., 2008). Most studies have documented increased animal movements across roads through observations of use, yet very few studies have quantified an increase in the viability and survival of wildlife populations before and after implementation of crossing structures. Without such comparisons, evaluation of the mitigation effectiveness of a crossing is not possible. Research methods for evaluation are far from formalized. Most research is primarily documented through photographic records or the footprint detection rather than quantitative modeling (van der Ree *et al.,* 2009). An important concern in evaluation of a facility is that considerable periods of time may be required before animals are sufficiently familiar with the structures to use them (Ball and Goldingay, 2008; Hunt *et al.*, 1987). Clevenger and Waltho (2005) have suggested that this period is normally two to four years. Consequently, the placement of many crossing structures lacks a strong experimental basis and, as such, conclusions regarding effectiveness of these structures are limited (Soanes and van der Ree, 2009; Taylor and Goldingay, 2009).

Even so, confidence in the field work carried out is increasing. Lister (2012) has evaluated mitigation structures and concluded that they successfully re-habituate landscape that was fragmented by a road network. Some studies have asserted that even a low rate of dispersal across a roadway using crossing structures is sufficient to reduce WVCs to an acceptable level and further reduce the probability of extinction of a local population (Lister, 2012; Taylor and Goldingay, 2009; van der Ree *et al.,* 2009). Lister (2012) explained that with appropriate design, mitigation measures can reduce WVCs by 80% to 100%. In another example, after the implementation of a mitigation facility the median population size of pygmy possum (*Burramys parvus*) was restored to 85% of its population prior to road construction (van der Ree *et al.*, 2009).

The inclusion of wildlife crossing structures in the design and construction of new roads and roads upgrades is increasingly common (van der Ree et al., 2009). They are built and implemented in a variety of sizes and designs. Europe has hundreds of wildlife crossing facilities—usually referred to as eco-ducts—while North America has relatively few (Lister, 2012). In response to public concerns over increasingly conspicuous WVC, government agencies have begun to include a variety of mitigation measures in their transportation planning and designs in some countries. The Transportation Equity Act for the 21st Century (TAE-21) enacted in 1998 as U.S. Public Law 105-178, expanded transportation enhancements (TE) funds use to support innovative financing alternatives, including projects to reduce vehicle-caused wildlife mortality (USDT, 1998). To date, however, WVCs have not always been included in safety analyses by transportation agencies (Huijser et al., 2009).

3.1.2 Reasons for a disciplinary combination

WVC is the most drastic manifestation of the conflict between development and conservation. Beier (1993) presented an example of such conflict: Interstate Highway 15 is constructed in the Palomar Range in southern California. This area is the only corridor for the local cougar (*Felis concolor*). The road presents a formidable barrier to wildlife movement, and removes the possibility for adjacent areas to supply immigrants to the cougar population in the Santa Ana Mountain Range. The highway, which has been constructed across a fauna movement corridor, has become a WVC hotspot.

WVC is seen as an inevitable result of road extension. However, these unfortunate accidents potentially could be mitigated. The ignorance of non-human species plays a significant role in increasing numbers of WVCs. Safe and efficient human mobility is the goal of transportation planning (Forman, 1998). As Lesbarreres and Fahrig (2012) stated, adding even a relatively small amount of money to road construction budgets for WVC mitigation measures remains low on the priority list for urban planners. This situation typically arises from the assumption that we cannot have a meaningful effect on road planning. A new vision for future transportation planning should involve ecological considerations and emphasize that “humans and wildlife share a common need to move” (Lister, 2012, p. 21). This ideology profoundly differs from the traditional one.

A single mitigation measure cannot accomplish much, however, no matter how iconic it is (Lister, 2012). Instead, mitigation measures must be planned at landscape scale to work as a system. Mitigation measures should be set in appropriate locations across a continent; this is why urban planners need to be involved in this work.

An analytic boundary has been observed between social and ecological spheres. The influence of human beings on wildlife, and vice versa, is recognized in the paradigms of social science. But the architectures of social and natural order are understood as maintained by relations and rules that are distinct to each sphere (Byrne *et al.*, 2002). Ecologists have developed a mature knowledge body around WVC, and have some experience with building, monitoring, and evaluating mitigation infrastructures. These studies, however, focus on ecological effects while generally ignoring anthropogenic causes, such as land use intensification and urbanization (Coffin, 2007). Traditionally, urban planning is carried out to satisfy human needs, ecological consequences are, at best, a residual concern. Lack of professional ecological knowledge creates difficulty when planners attempt to develop successful mitigation strategies. Assessments completed to date suggest that nonfunctioning mitigation measures are prevalent. Failures (temporary or permanent) appear to stem from inadequate consideration of placement, architectural design, and behavior of target species (Woltz *et al.*, 2008). Better resolution of wildlife–development conflicts requires that ecological knowledge be integrated with urban planning. An interdisciplinary research approach is imperative for developing effective solutions, because ecology or social science alone cannot provide complex information about development influences on wildlife (Niemela, 1999).

Current knowledge and models provide theoretical and practical tools to improve WVC-avoidance planning. This literature review, however, highlights the necessity of developing a transdisciplinary knowledge body to bridge the existing gap. As Coffin (2007) stated, although sustainable urban planning has developed steadily since the 1960s, this work is only beginning to find its way into WVC mitigation (Forman *et al.*, 2003). Answers about how best to mitigate WVC have to come collectively from government officials, landscape planners, architects, transportation experts, ecologists, and residents. Clearly there is potential for a collaborative effort both in practice and research.

3.1.3 Potential contribution of this research

The unique perspective of this study is to narrowing the research gap by using species' behavioral patterns to develop mitigation strategies.

WVCs result from inappropriate and unmanaged interactions between wildlife and traffic. To minimize impacts, focus should be split evenly between these two factors. Introducing knowledge of wildlife behavior to planners increases the possibility of eliminating WVCs in the future.

3.2 Conceptual Framework

This research is carried out under the macro concept of sustainability. From the perspective of urban planning, WVC mitigation emphasizes decreasing the negative

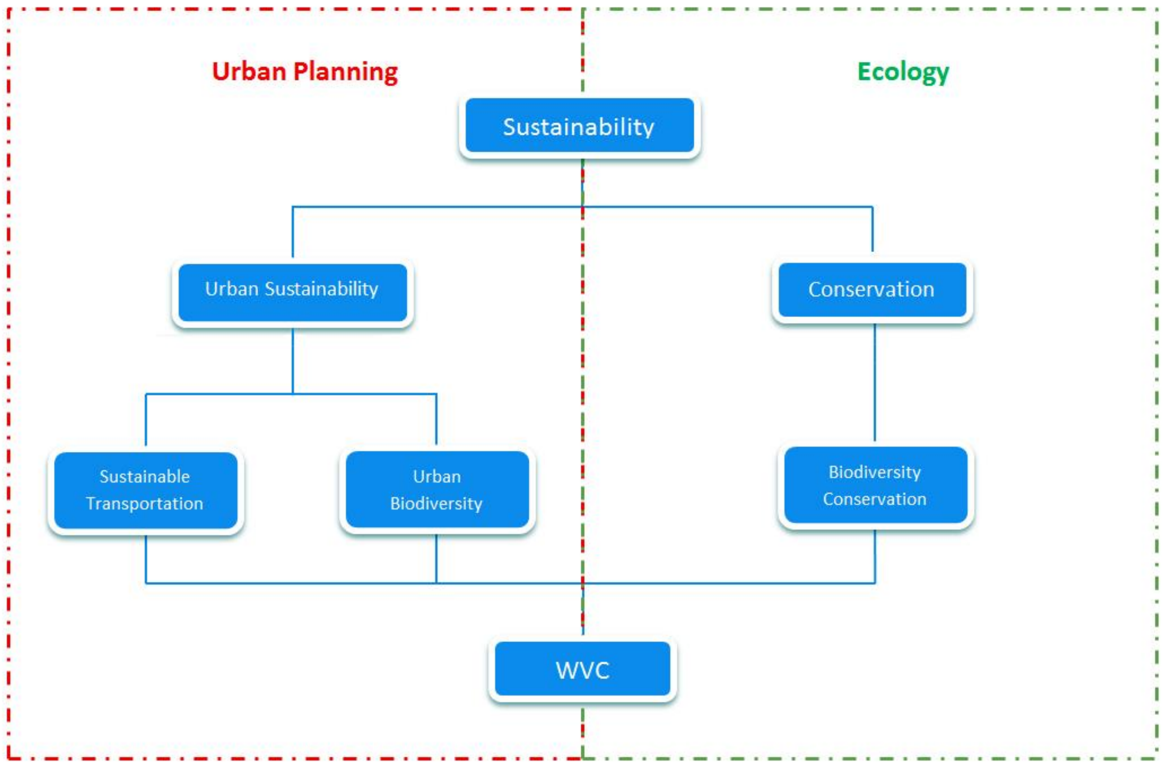

Figure 3.1: Conceptual Framework
Source: prepared by the author.

impacts of roads; from the perspective of conservation, it aims to protect wildlife from the disruption of roads. As a result of the interdisciplinary attributes of WVC, two concepts—urban sustainability and deep ecology—are used as guiding ideologies to address this issue and provide a methodology to seek solutions. This section will address the merits and demerits of the two theories in a conceptual framework (Figure 3.1) which will help us to understand the nature of the WVC problem and to find appropriate solutions.

3.2.1 Urban sustainability

Sustainability is presented with a wide context; generally, it refers to a long-term stable relationship between human and environmental systems (Alberti, 1996). A United Nations Conference in the 1980s described the need for a development paradigm based on this new term (Wheeler and Beatley, 2009). When applied in urban planning, sustainability influences multiple dimensions such as land use, urban design, transportation, environmental justice, architecture, building construction, environmental planning, resource use, and urban ecology.

Planners face tough decisions about where they stand on protecting the ecological environment, promoting economic growth, and advocating for social justice. Sustainability offers an alluring, holistic way to evade these conflicts (Campbell, 1996). Sustainability stimulates a new planning pattern that integrates environmental considerations into planning procedures. The ecological dimension of a city is emphasized by many scholars in the process of creating a sustainable environment. In the late 19^{th} and early 20^{th} centuries, urban reformers and humane activists articulated a vision of community that extended beyond humans. In this view, cities were reshaped into sites for the performance of charity and compassion for the weak. Since then, a variety of theories have been developed under the influence of this concept, such as smart growth, new urbanism, ecological cities, low impact development, and so on (Benson, 2013; Jabareen, 2006; Newman and Jennings, 2008).

Sustainability is inadequate, however, for solving problems when non-human species are involved. The concept of sustainability is built on an optimistic hypothesis that economic development and environmental conservation can work in harmony, and relies on technology to extend the environmental resource base to accommodate future growth (World Commission on Environment and Development, 1987, York, 2003). John Byrne *et al.* (2002) impressively describe the intrinsic flaw of sustainability (p. 286):

> *The contemporary world political presumes that sustainability is a scientific, technological, and economic matter. Although, this presumption is typically manifested in economic terms and thus continues to be most concretely presented in discussions of trade-offs between environmental protection and material progress, its deeper implication is the demise of any idea of the inviolability of nature.*

All environmental components are discussed in term of economics or resources. As Lafferty (1998) stated, the concept of sustainability fails to touch the root of the environmental problem but attempts to theoretically obscure the basic contradiction between the finiteness of the earth, with a natural self-regulating system operating with limits, and the expansionary nature of industrial society. According to how it was defined in 1987, sustainable development needs to meet the need that represents the dominant worldview of technocratic-industrial societies. Aligned with traditional development patterns, this concept regards humans as isolated and fundamentally separate from the rest of nature; as superior to the rest of creation (Devall and Sessions, 1985).

Applied in urban planning, this ideology affects planning research and practice significantly, with devotion to human welfare. It develops ecology as a science that provides rules for engineers, and provides a sound basis for action by those who would manage the environment. This premise presents a formidable obstacle to solving environmental problems, especially when wildlife is involved. Various kinds of wildlife have their own lifestyles and movement models, and cannot be treated simply as resources. As Devall (1980) commented, sustainability feels reform, while necessary, is not sufficient.

Sustainability[8] is light green. Light green ideology produces instrumental environmental policies that respond to clearly defined threats to domestic public health. By contrast, dark green ideology expresses an environmental ethic—one that encompasses, but goes beyond, domestic health, safety, and amenity concerns (Vogel, 2001). Dark green advocates the scaling down of civilization to preserve Earth's wildness and biodiversity. Directed by this ideology, our first ecological priority must be to preserve all the species, sub-species, varieties, communities, and ecosystems that we possibly can (Worster, 1995).

A new paradigm is required to supply a new conceptual and philosophical base and a new environmental ethic to address the negative impacts of development on wildlife, including WVC. Thus, the concept of deep ecology is introduced to address the deficiencies of urban sustainability.

3.2.2 Conservative biology

Biological and ecological knowledge, which is intended to lead to recommendations for action, is widely employed in situations of economic or social interest to mankind; this knowledge also engages and inspires decision-makers, communities, and individual supporters to protect wildlife and wild places. This provides the content of applied ecology. This kind of ecology is a practical and intellectual

[8] Upon a capital approach, there are "weak sustainability" and "strong sustainability". Weak sustainability states that "human capital" can substitute "natural capital" while strong sustainability assumes that "human capital" cannot substitute "natural capital". However, neither of the two paradigms expresses an environmental ethic. Thus both are realized as light green.

approach, a discipline, rather than a coherent body of generalized knowledge. During the past 30 years, new frontiers have been explored in applied ecology—land use and development surveys, conservation and management, the exploitation or control of invasive plants and animals, and so on (Soule, 1986). In practice the distinction between pure and applied ecology is one of convenience and not of scientific merit or status (Bunting and Wynne-Edwards, 1964).

Conservation is an important subdiscipline of applied ecology. The Earth is losing its diversity of life at a rate higher than at any time in human history (Reid, 1995). The extinction rate was approaching 1000 times the background extinction rate in the 20^{th} century (Environment News Service, 1999), and continues to increase. The International Union for Conservation of Nature (IUCN) added more species to its Red List of Threatened Species in July, 2012 and revealed that about 31% of global species are currently threatened with extinction, with 6% being critically endangered— the final classification prior to extinction. In addition, 9% of the global species are listed as endangered and 16% are vulnerable (Knight, 2012). The dramatic loss of wild ecosystems, which has been noted by conservation scientists as the sixth mass extinction, has contributed to poverty and starvation, and will reset the course of evolution on this planet (Center for Biological Diversity, 2016). More than species loss, however, conservation scientists note that the sixth mass extinction is a biodiversity crisis requiring far more action than a priority focus on rare, endemic, or endangered species. Concerns for biodiversity loss cover a broader conservation mandate that looks at various ecological processes, such as dispersal, migration, demographics, effective population size, inbreeding, etc**.** (Molnar *et al.*, 2004). Every species makes an irreplaceable contribution to genetic, species, and ecosystem diversity within an area, biome, and planet.

Since the mid-20th century, conscious efforts have targeted individual species and their natural habitats for conservation (Rabinowitz, 1986). The emergence of the term conservation biology helped to crystallize the modern era of conservation (Cooke *et al.,* 2013). Soule (1986) characterized conservation biology as a value-based and crisis-oriented discipline by writing that "its relation to biology, particular ecology, is analogous to that of surgery to physiology and war to political science…. Biologists can help increase the efficacy of wildlife management; biologists can improve the survival odds of species in jeopardy; biologists can help mitigate technological impacts". This science requires its practitioners to act before knowing all the facts and to tolerate uncertainty (cited in Wiederholt *et al.*, p. 437).

Conservation biology is an interdisciplinary subject drawing on natural and social sciences, grounded in the assumption that science can provide both the advice and the motivation needed for people to start acting in a new way (Haila, 1999). As a discipline, it reaches beyond biology into subjects such as philosophy, law, economics, anthropology, arts, and education; however, biology and ecology are of primary importance to the practice and profession of conservation biology (Groom *et al.*, 2006).

Conservation science is a field that has inherently included human values from its inception and conservation decisions are often influenced by values of scientists, as well as the general public alike (Wiederholt *et al.*, 2015). As Takacs noted, "we can find in it what we want, and can justify many courses of action in its name" (Takacs, 1996, p. 99). Science is not a neutral witness in conservation biology, both reason and sensitivity are essential to accomplish the conservation mission. Conservation biologists work in a scientifically ethical manner to seek an equitable solution for ecosystems and society. They advocate measures that will deliver the greatest good for the greatest number of people for the longest time. Some conservation biologists who fall into the dark green camp, such as Aldo Leopold (1949), have emphasized that nature has an intrinsic value that is independent of anthropocentric utilitarianism.

3.3.3 WVC as an interdisciplinary subject

The presented conceptual framework shows that this research will explore solutions for WVC through an interdisciplinary approach under a wildlife-friendly ideology. Knowledge and ideology are essential for this research. An interdisciplinary approach is appropriately applied in this research because WVC has been neglected in the traditional disciplinary structure of transportation planning. WVC reflects a conflict between humans and wildlife, and can be understood only by combining the perspectives of planning and ecology.

Understanding WVC involves combining several academic disciplines. Development of mitigation measures requires scientific knowledge from transportation planning, architectural design, and conservation biology. Researchers from different disciplines pool their knowledge and approaches and modify them so that they are better suited to this problem. Such combination encourages not only the cooperation of planners and ecologists to work toward a common goal, but also the introduction of methods and insights from other disciplines to traditional fields of study.

Mitigation measure development requires scientific knowledge from multiple disciplines; implementation of the measures requires a dark green ideology that is more wildlife friendly than the current dominant one. The socially constructed view of nature traps planners in a classic battle of man versus nature (Campbell, 1996).

An ideology with sentiment for wildlife ensures better consequences of WVC mitigation strategies by setting a lower threshold of implementation, increasing budgets, and making stricter regulations. Mumford (1974) noted that the fatal weakness of religions is they create a coherent transcendental world picture that did sufficient justice to the existential and subjectively unalterable facts of human experience. However, this weakness is overcorrected by the organization of physical and corporeal activities (Mumford, 1974).

The concept of sustainability puts an end to this tendency toward mindlessness by advancing a development pattern that does not compromise the ability of future generations to meet their own needs. The world is facing an environmental crisis of historic proportions, however, and that crisis calls for sensibility that would reconnect people to the physical world (Gore, 2007). Deep ecology, as a dark green ideology, encourages humanity to encompass all life forms on Earth. Neither an entrenched prejudice nor an extreme sentimentality, however, contributes to an ideal conservation outcome. Seeking a balance between them is necessary.

Chapter 4

PARADIGM SHIFT

This chapter addresses the reasons for and necessity of spurring a paradigm shift in mitigating WVCs. A paradigm mode for science was first presented by Thomas Kuhn (1962) in his work *The Structure of Scientific Revolutions*. Introducing a new paradigm to a scientific community opens up new understandings that scientists had never before considered valid (Kuhn, 1962). As discussed earlier, the unsatisfactory state of WVC mitigation is largely due to an anthropocentric ideology that traditionally has dominated planning. This research addresses the problem with the current paradigm, and then advocates a new paradigm that supplies stronger motivation and defines more efficient solutions for WVC mitigation.

Scientific progress changes relationships between humans and other life forms. In hunter-gatherer societies, humans obtain their food directly from nature by hunting wild animals and collecting wild plants. The ability of hunter-gatherer societies to coexist with wildlife is attributable to their attitudes and beliefs toward nature, which are often termed animism. Agrarian societies tend to have greater negative impacts on wildlife because their mode of procuring food involves manipulation of natural ecosystems. Since then, human society has been distancing itself from the natural world. As techniques for planting and harvesting become more advanced, nearly all food comes from human-manipulated agricultural ecosystems, while natural ecosystems provide only a small proportion of food. Denser human settlements may over-exploit wildlife in their surroundings. Agrarian societies, however, are generally confined to certain habitat types and maintain large undisturbed areas that provide habitat for wildlife (Orland, 2015).

The overwhelming influence of science is embodied by the Industrial Revolution. Three hundred years of industrialization have dramatically changed social and ecological relations (Byrne *et al.*, 2002). Science offered humans an unprecedentedly quick way to achieve an economic boom, as well as significantly improve the human ability to dominate nature. Overwhelming technology significantly changed human society, and the human worldview has become obsessed with economics and endless growth. Social science is distinguished from natural science as if they were two separate realms of reality. Science is an agent that actively strives for domination over nature and a tool to break limits set by nature (Haila, 2000). Industrialization brings a series of natural and social problems, but science is seen as a panacea for them. As Buckminster Fuller claimed, technology has given us the power of God (cited in Sessions, 2014. p.110), it also gives humans the ability to disrupt original ecological patterns and mechanisms. “Formerly man had been a part of nature, now he was the exploiter of nature” (White, 1967, p. 1204). During that period, techniques and rationality were brought into every area of human life, including the social sciences.

Humans exert power over nature, including over other life forms. The attitude of humans toward other life forms, however, is determined not only by the development of science, but also by the human value system. Domination and exploitation have been referred to as anthropological constants by philosophers and sociologists such as William Leiss, Max Horkheiner, and Edmund Husserl (Leiss, 1974). This constancy is the driving force in the development of science and technology. Leiss recognized that the modern era in Europe brought about a critical shift in the relationship between humans and nature (Haila, 2000). Some authors feel that positions of human domination of nature and subordination to nature have thrived simultaneously throughout most of human history (Passmore, 1980).

It is difficult to determine which attitude has been constant in human history, and if this all-encompassing attitude had ever changed; if it had ever changed, it is also difficult to determine at which point it changed, and whether it changed completely, or has changed only in details (Haila, 2000). Since the 1960s when *ecological crisis* entered the vocabulary of Western environmentalism, there has been a widely accepted conclusion that the progressive, secular, materialist philosophy on which our modern life rests is destructive to the whole fabric of life on the planet, and that human–nature dualism is harmful and should be challenged (Haila, 2000; Worster, 1995). This change in an ethical values system, which is necessary to explore an efficient WVC mitigation strategy, is called a paradigm shift in science.

4.1 Scientific Paradigm Shift

4.1.1 Subjectivity in science

Mumford (1974) has described the minds of humans as "a mystery as profound as the forces that bind together the components of the atom and account for the character and behavior of the elements" (Mumford, 1974). The human mind orients scientific activities in an appropriate direction to help to attain its essence: humanity (Habermas, 1971). Human mind is woven into the fabric of science and is a crucial part of the structure of science. A human mind cannot be probed by any instrument but it finds expression in the value system of humanity. The manifestations of the value system are embodied in religion and art, in ritual and social custom, and also in science.

The human value system, which should provide enlightenment, was replaced by instruction in control over nature and objectified processes at the beginning of the Industrial Revolution (Habermas, 1971). Technology overthrows everything that prevents the internal logic of its development; it reduces the human being to "a slug inserted into a slot machine" (p. 135). This machine stabilizes its own equilibrium and programs autonomously (Habermas, 1971). The laws of self-reproduction demand that a society looks after its survival on the escalating scale of continually expanded technical control over nature.

We are unavoidably influenced by technology, as McLuhan remarked, "we shape our tools and afterwards our tools shape us" (cited in Lapham, 1995. p. 343). However, it is human to determine the way to use technology, when to use it, and whether to use it; humans also intervene in technological developments. As Sarah Miller (1997) stated, there is a loss of human involvement in the shaping of technology and society; this shaping fails to take into account that the human mind is not fixed and human society is dynamic (Green, 2002; Miller, 1997). Therefore, even significantly affected by technology, it is human subjectivity and conciseness rather than technology that determines the development of culture and science.

Scientific activities fall into two categories: the first investigates facts or develops tools; the second evaluates the results by some moral or cultural standards. Both categories are unavoidably affected by human subjectivity, preferences, and choices. The ideological bias of individuals or groups may bend truths to make them support an idea or an interest. Ideological bias is more prevalent in social sciences, which lack a prevailing paradigm. This characteristic of social sciences blurs the demarcation between truth and falsehood. Schumpeter (1949) described the scientific system as a combination of facts and value judgments. Knowledge not only contains observed facts and propositions, but also interpretations from our predecessors as well as in ideas that float around us in the public consciousness. Social science is full of human ideological bias (Schumpeter, 1949).

4.1.2 A paradigm pattern

The development of a science and the knowledge that it produces is not divorced from a social context (Foster, 2008). Each is deeply affected by the dominant value system in a specific historical period. Ideas are hidden in research, but it influences the practice of research and must be identified (Creswell, 2003). Thomas Kuhn (1962) adopted the concept of a *paradigm* to explain the subjective impulses and motivations hidden in research.

Paradigm explains people's feeling that warrants and reinforces the move from motivation to action. A paradigm determines and produces various concepts, laws, theories, and views in natural and social sciences. Every stage of the development of a scientific paradigm is modified by dreams, wishes, impulses, and religious motives that spring directly, not from the practical needs of productivity, but from man's unconscious (Mumford, 1974). A prevailing paradigm sets up a unified standard for the whole scientific community, which makes its members work on the same problems. Within those areas to which the paradigm directs the attention of the group, science leads to "a detail of information and to a precision of the observation-theory match that could be achieved in no other way" (Kuhn, 1962, p. 498).

4.1.3 Paradigm shift

The development of a paradigm is an evolution from weak to strong, and to being weak again, which is analogous to a life cycle. Before the paradigm pattern is formed, the science province is in a state of disorder and diversity, called by Kuhn (1962) the pre-paradigm state. During this period, a number of paradigm candidates coexist and compete with one another. When one of the paradigm candidates occupies the dominant position and unifies the scientific world, the paradigm phase is coming (Kuhn, 1962).

A full cycle of paradigm shift consists of four phases.

1. **Paradigm phase**. At this stage, one paradigm wins the competition because it is more successful at solving puzzles. In the beginning of this period, the paradigm may be accepted by only a minority in a scientific community, but later it will be extended and developed. Meanwhile, scientists become less tolerant of other theories. The new paradigm presents guidance for the community to do further research and sets up a new world view for its members. No challenge to the principles is allowed until an anomaly emerges.

2. **Crisis stage**. When an anomaly is acknowledged by the majority of a scientific community, the paradigm will experience a series of attacks from members who were its advocates. Early attacks may put the focus on paradigm rules; but following attacks will involve some minor or not so minor alternate articulations of the paradigm. Through this proliferation of divergent articulations, the rules of the paradigm will be broken, and finally the paradigm will be abandoned by the group (Kuhn, 1962).

Normal science is a puzzle-solving process. When an anomaly emerges, the scientific community expects a modification of the existing paradigm. When the anomaly is significant enough, a crisis will emerge and initiate a paradigm shift. As Kuhn (1962) presented, if an anomaly has the potential to develop into a crisis, it must be more than just an anomaly. Normally there is a long period between the disappearance of the old paradigm and the establishment of a new paradigm. In this sense, a crisis not only acts as motivation to wreck the old paradigm, but also provides essential data for a paradigm shift.

3. **Revolutionary stage**. A crisis serves as a prerequisite to a revolution. In the revolution stage, a number of paradigm candidates emerge. The state of the scientific community at this stage is similar to that in the pre-paradigm period. When one of the candidates wins the competition, the revolution stage comes to its end. A new paradigm may emerge before a crisis has fully developed. Individuals who are young or new to a community tend to challenge the world view and rules determined by the old paradigm.

4. **New-paradigm stage** When the old idea has gone far enough, a new constellation of ideas, a new whole culture, and a different cast of characters will occupy the center of the stage and present a new drama (Mumford, 1974). Eventually a new paradigm is formed. The new paradigm is not an articulation or extension of the old one. It totally changes the way people think about or interact with things. It reconstructs the scientific community and changes the basic ideology of the field. When the new paradigm is set up, the view, methods, and goals of the profession will be significantly changed.

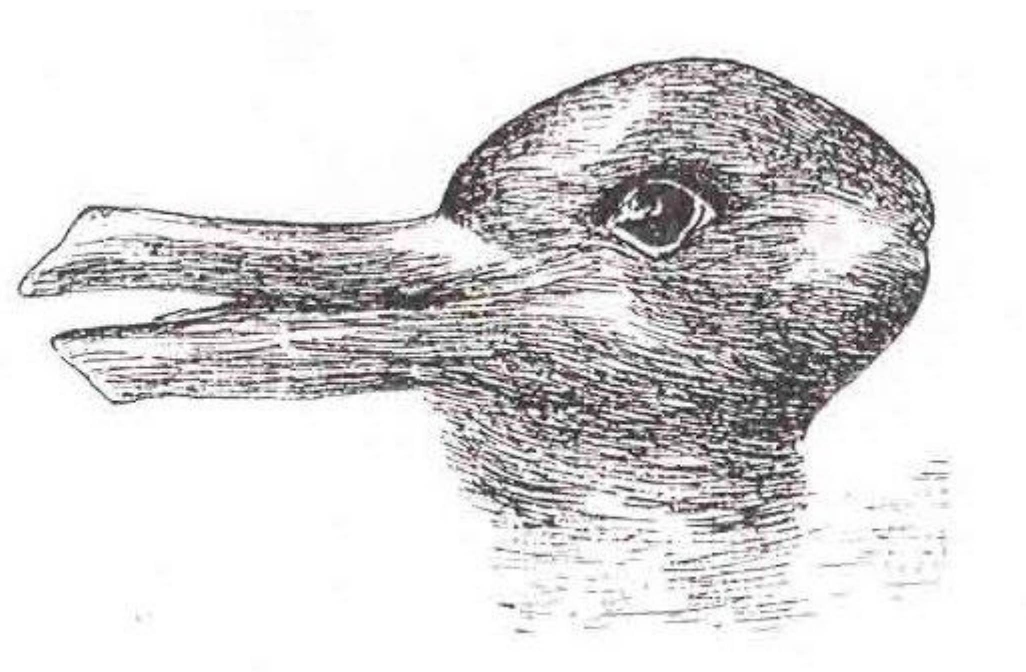

Figure 4.1: Duck-rabbit optical illusion used by Khun to demonstrate the way in which a paradigm shift could see the same information in an entirely different way Picture source: https://upload.wikimedia.org/wikipedia/commons/4/45/Duck-Rabbit_illusion.jpg.

Thomas Kuhn (1962) presented two necessary conditions to spur a paradigm shift. First, an achievement is reached that successfully attracts an enduring group of adherents; second, the new paradigm is sufficiently open-ended to leave all sorts of problems for a redefined group of practitioners to resolve (Kuhn, 1962). In the early stage of the development of a paradigm, the emergence of alternatives is easy; when the prevailing paradigm is fully developed, its tolerance toward the alternatives becomes lower; when a paradigm becomes weak, a crisis emerges and one of the alternatives may become stronger and finally substitute for the old paradigm.

4.1.4 Paradigm shift in sociology

A paradigm shift in social science is not as drastic as in natural science. In most cases the paradigm exists as a cumulative effect. According to the Kuhnian paradigm shift theory, a theory becomes a prevailing paradigm only if it could substitute for all other alternatives. Once a prevailing paradigm is set up, the preceding antitheses are abandoned, and all other antitheses are ignored or neglected (Bronfenbrenner, 1971). However, Kuhn's paradigm model is suggested to be modified when it is adapted in social science. In the history of social science, it is dialectics rather than a substitution that acts as the main method of development. This means that the emergence of new theories does not lead to the abandonment of old ones. Dialectics hints that there exist more than one prevailing theories at the same time in a scientific area. Substitution in social science only occurs in some extreme situations. The new theory often emerges as a compound, or a mixture of the old ones. A dialectic state is a more commonly seen method of paradigm shift than an obvious shift from old to new. The relationship among the co-existing theories is sophisticated—they may contest, contrary or complement. In this research, the relationship between the two paradigms—anthropocentrism and ecocentrism—is complementary to each other.

A social science paradigm is an expression of the dominant value system. It is impossible for social scientists to set up a unified standard to judge right or wrong. People have to make choices among different paradigms based on faith.

The emergence of a new ideology is relatively easier in a social science than in natural science. However, to make itself visible and acceptable to the majority of a community, a value system needs to undergo a long period of incubation and experimental testing. When it gains support from the majority of a community, it will be a part of a stable tradition and be put in a system of education. Through continual institutional extension, this value matures enough to make significant social changes.

Social science deals with much more complicated objectives than does natural science. The aim is not only to alter the way we look at the world, but also to alter the world. Social scientists not only work on puzzle solving but also work to persuade ruling authorities to enforce their theories. In applied science, a paradigm not only affects the scientific community, but also the public—it is realized through a process of incorporation: at first the gap between the original apparitions and intuitions and public life is bridged. Then ideas are spread from an internal, private environment to a public world. Finally, ideas are materialized through transformation of the physical environment by practical means and symbolic expressions (Mumford, 1974).

4.2 The Problem with the Current Paradigm in Urban Planning

Social science deals with a dynamic social structure and diverse value systems and, thus, it lacks a prevailing paradigm in its different branches. A theory may be accepted in one domain but denied in others. In addition, the participants in social science are not only scientists but also all citizens, with their different backgrounds, so it is impossible to set up a consensus that consolidates the loyalties and commitments of all participants (Wolin, 1968).

The goal or urban planning is to alter the future, an inherently value-based decision process – this means it is informed by social paradigms. This paradigm determines how the resources will be allocated during the goal-achieving process. There are three existing dimensions of the planning goal: social, economic, and environmental. The topic of this research belongs with the third one.

The previous chapter reviewed a number of planning theories, which aimed to preserve the urban ecological environment; however, most of these green theories are too light to generate efficient planning policies in practice. They are still affected by anthropocentrism, which entails a human–culture dualism. Anthropocentrism is shared by many branches in social science. This ideology has been a dominant paradigm in modern western thought since Descartes. It justifies the human domination of nature. Although this ideology is too comprehensive to generate tactical concepts, theories, or principles, it deeply affects thought patterns and decision-making processes. As a result of the domination of this ideology, planners are often in conflict with environmentalists and ecologists over urban ecological conservation issues.

This paradigm does not create a supportive environment for WVC mitigation. Planning agencies are focused on building bigger, better, safer and more efficient roads to cater for growing demand for vehicle movement. Although planning agencies are being challenged to respond to community and government expectations to protect the environment, environmental issues are not on their priority list. When developing WVC mitigation plans, the questions still remains, 'is it feasible or reasonable a mitigation measure for a particular species?' 'Is the measure of good value?' 'Can it be constructed without compromising the objectives of the road?' (Roberts and Sjolund, 2015).

4.2.1 Anthropocentrism is the root of city—wildlife conflict

Environmental problems, similar to other types of social problems, rise to public attention through a process of claims making, in which particular social actors promote views that are contested by other social actors (Haila, 1999). There is an anthropocentric ideology rooted in the fundamental struggle between human civilization and the threatening wilderness that expresses itself in various ways.

Cities have a long tradition to be planned as locations where production, consumption, distribution, and innovation take place. A city is in competition with others for markets and industries (Campbell, 1996). A city is planned to meet human needs, while hardly considering the welfare of other life forms. Wildlife suffers habitat loss, pollution, invasive species, and numerous other disturbances, and the structure of native vegetation is also frequently altered. For example, trees within 50 m of a house are thinned to create a defensible space against wildfire (Theobald *et al.*, 1997). In addition, ecological impacts of cities extend far beyond the urban fringe to surrounding rivers, the ocean, and the atmosphere (Platt, 1994). Roads as an urban infrastructure extend far from the urban fringes and go deep into the wild. They disturb the larger ecosystem upon which all species depend by disturbing the spontaneous harmonies of nature.

Urban development is open to human-wildlife conflicts. Various environmental conservation efforts are made to solve these conflicts. Economic standards are widely used as an indicator to transform environmental problems into policy. The most common method is the cost-benefit analysis. Economic indicator allows cross-sectoral decisions, and it act as an indicator to prove whether environmental policy fits the needs of public preference (Brauer, 2003). Economic analysis has had its successes and made its contribution; it offers a way for us to reach a given environmental goal most efficiently and cheaply (Ackerman and Heinzerling, 2002). However, this evaluation method is realized quite problematic in principle for three reasons. First, nature is not for bought and sold. Most cost-benefit analysis places use values (direct values) and non-use values (indirect values) on natural assets. Use values refer to consuming value, as well as ecological services; non-use value refer to the existence of a value even though individuals do not intend to sue the resource but feel a ‘loss’ if it would disappear (Brauer, 2003; Nunes and van den Bergh, 2001). In this analysis framework, the non-use value, which refers to the intrinsic value of life is interpreted incompletely. The monetized cost and benefit excludes questions of fairness and morality. Second, some environmental damage, such like wildlife and biodiversity loss, is irreversible. Understanding the irreversibility reveals limitations in the economic valuation process (Solomon *et al*., 2009). Third, as a market valuation mechanism, this approach focuses on increasing efficiency—on getting the most desirable results from the least resources. Nevertheless, the objective of environmental policies should be effectiveness rather than efficiency. Consequently, the standard economic approach to valuation suffers from some fundamental flaws so that it is inaccurate and implausible. Without a doubt, a fully economic valuation will subject to much scientific debate due to that these non-market resources cannot be analyzed in an economic framework. This decision-making process must make some room for non-quantitative considerations (Ackerman and Heinzerling, 2002).

4.2.2 Shallowness of the dominant urban ecological theories

Beyond this mainstream ideology, there are some voices calling for wildlife conservation during the process of urban development. As early as 1865, George Perkins Marsh addressed the human impact on nature—in modern terms, cities' ecological footprints—in his treatise *Man and Nature, or Physical Geography as Modified by Human Action* (cited in Platt, 1994). Marsh made a pioneering attempt to awaken the public to the danger of imprudent operations and to present suggestions to restore the spontaneous harmony of nature (Marsh, 1865, p. Preface: III).

Inspired by the utopian novel *Looking Backward* (Bellamy, 2008) and by Henry George's (1886) work *Progress and Poverty*, Ebenezer Howard presented his Garden City model—a "combination of town and country…" to retain the "free gift of Nature—fresh air, sunlight, breathing room and playing room" in growing cities (Howard, 2008, p. 113). In his model, to a large extent urban green spaces are planned to create a rural atmosphere rather than to preserve decreasing ecological space. Howard's opinion appealed to proponents of the City Beautiful Movement, which flourished concurrently. Urban green space was realized as necessary in every city by these like-minded professionals, not only to balance the paved areas of streets and sidewalks, but also as a channel to resist squalor, density, ugliness, and oppression, and even to help to create urban virtue. The landscape architect and reformer Frederick Law Olmstead and his associates invented the well-known park and boulevard system to embody the philosophy that the beauty of urban open spaces creates peace and health for city dwellers (Harrisburg's Old 8th Ward, 2012; Platt, 1994). Directed by purely aesthetic neoclassicism, urban green spaces are designed to supply visual pleasure with interminable lush greenery and rows of mature trees spaced at equal distances from one another (Van Nus, 1975). The narrow view of beauty as orderliness overemphasizes urban embellishment while ignoring the biodiversity potential of an urban area. Only with the growth of environmental movements did urban ecology gain attention. Pioneered by Richard Forman, ecological terms and theories were introduced to the field of landscape ecology to describe the ecological value of urban lands. Some planners started to focus on sustaining natural regenerative processes. In the 1970s the importance of urban biodiversity gained wide public awareness, and ecological knowledge started to be imported into the planning area and applied to landscapes in and around metropolitan areas (Beatley, 2009). The planning department came to the defense of nature through the work of park planners, eco-city proponents, green-belt planners, and modern environmental planners (Campbell, 1996).

Since the 1980s, *sustainability* has been introduced to urban planning. A plan, policy, or strategy is evaluated against the criterion of acting toward future generations. Urban sustainability has become a common goal of all the different branches of social and natural sciences. As a long-range goal it is a worthy one, for planners do need a vision of a more sustainable urban society. Critics of this concept point out that it sets a goal far into the future, and even currently conflicting interests will seem to converge along parallel lines over a long time; and that sustainability is too malleable—it means many things to many people without requiring a commitment to any specific policies. Sustainability becomes a parameter of the debate, almost certain to be integrated into any future scenario of development (Campbell, 1996). Until now, planners have not had concrete strategies to achieve sustainable development.

This environmental consideration is still human-centered. Anthropocentrism, which views humans as separate from and superior to the rest of nature, is the root of the environmental problem because it leads to the growth dependence and, more important, it separates human society from natural systems. Cities are a main method for realizing this rift (Marx, 1906; York, 2003). Nature, in this paradigm, is only a storehouse of resources, which should be developed to satisfy the ever-increasing numbers of humans and their ever-increasing demands (Devall, 1980). This ideology is disastrous not only for most non-human life forms but also potentially for the human race itself.

Environmental problems attended to by sustainability proponents because they destroy ecosystem integrity, reduce biodiversity, occupy habitat, and pump CO_2 into the atmosphere, which will in due course compromise human existence. The obsession with human benefits calls into question whether these theories can develop a useful model to guide wildlife preservation planning practices. Unlike indigenous, sustainable communities, the modern people choose an environmentally friendly practice voluntarily, because there is no immediate survival or market imperative to do so (Campbell, 1996). Thus, a spiritual transformation is the prerequisite for an environmental transformation. As Worster (1977) stated (p. 338):

> *All science, though primarily concerned with the "is," becomes implicated at some point with the "Ought." The continuing environmental crisis makes it obvious that man's moral visions and utopias are little more than empty enterprise when they depart too far from nature's ways. This is the major lesson we have learned from studying the effects of men's hands on environment. An ecological ethic of interdependence, man in nature may be the outcome of a dialectical relation between scientist and ethicist.*

4.3 Implications of Deep Ecology as a Complementary Paradigm in Urban Planning

4.3.1 Deep ecology

According to terminology that is currently popular in American universities, a distinction must be made between shallow or environmentalist ecology, which is based on the old anthropocentrism, and deep or biocentric ecology. To deal with human–wildlife conflicts effectively in urban areas, we must take a step in the direction of deep ecology, which attributes moral significance to certain nonhuman beings. In the framework of deep ecology, anthropocentrism is thus discredited, because animals afforded the same consideration as men, within the sphere of moral consideration.

The concept of deep ecology was coined by the Norwegian philosopher Arne Naess in 1973. He stated that man in the environment is one of the knots in the biospherical net, which is woven by all organisms. Once the net does not exist, all the knots are no longer the same things (Naess, 1973). Economics is treated as a small sub-branch of ecology and will assume a rightfully minor role in this new pattern. The "Four Changes[9]" essay, published by Gary Snyder in the 1970s, is one of the most prominent statements of deep ecology (Devall, 1980). This ideology advocates biocentric equality, which sharply contrasts with anthropocentrism as a world view dominating technocratic-industrial societies.

Charles Taylor (1985) views humans as "self-interpreting animals" (cited in Haila, 1999. p. 167). Whatever human beings do is influenced by their view of themselves (Haila, 1999). American environmentalist Aldo Leopold (1949) expressed this intuition when he said humans are plain citizens of the biotic community in *A Sand County Almanac*. This self-interpretation gives us a reason to respect all human

[9] The Four Changes essay addresses three prominent American shortcomings: population, pollution, and consumption. Snyder presents solutions based on a transformed culture from "the five-millennia-long urbanizing civilization tradition into a new ecologically-sensitive, harmony-oriented, wild-minded scientific/spiritual culture".

and nonhuman individuals in their own rights instead of setting up hierarchies of species with humans at the top (Devall and Sessions, 1985). Tom Regan (1985), author of a famous essay entitled *The Case for Animal Rights*, defended the notion that an animal is the subject of its own life. An animal possesses the right to live; that is to say, concretely, the right not to be deprived by others of the pleasure of its own future (Ferry, 1995).

Deep ecology emphasizes the powerful spiritual link between humans and nature, reminding us of the interdependency of species and showing us how different life forms interact with one another and their environments in a complex web of connections. This perspective stresses the connections among species, including humans, and to the environmental conditions that support all life on earth (Campbell, 1996; Ernst, 2009). Yrjo Haila, a more extreme deep ecology advocator, insisted that there is no difference between ecological and social processes. Both are regular parts of the energy-conversion process in an ecosystem (Haila, 1999; Haila, 1998a, b). Haila explained this point in this way (Haila, 1999, p. 170):

> *…we cannot objectify everything. But then the boundary between us and the rest of the world becomes blurred. It is the act of objectification that creates the boundary. Dualism between us and the world, culture and nature, seems necessary in order that we be able to do or think anything at all…*

As a philosophy brimming with feminine emotion, deep ecology rethinks the idea of nature and sees its appreciation as a historically evolved sensibility (Campbell, 1996). Unlike light green ideologies, deep ecology is based less on a responsibility-based approach and more on a rights-based approach. It argues for an ecocentric world view that puts the Earth first (Ernst, 2009; Sessions, 1992). This ideology is realized as a paradigm shift rather than reformist environmentalism because it attacks the premise of the anthropocentrism paradigm and attempts to present alternatives of thinking (Kuhn, 1962; Devall, 1980).

Although we turn to natural science to understand the context, dynamics, and effects of human–wildlife conflicts, we must turn to social norms to decide what balance is fair and just (Campbell, 1996). There is some controversy around whether deep ecology is operational. Some critics of deep ecology insist this concept is too spiritual and religious to be the rules of the game. Deep ecologists have limited themselves to critiques of the dominant social paradigm and to suggesting alternative visions of man-in-nature without specifying how these visions may be realized (Devall, 1980). On the other hand, supporters of this ideology including William Ophuls, E.F.Schumacher, George Sessions, Theodore Roszak, Paul Shephard, Gary Snyder, and Arne Naess, have in one way or another expressed the hope that deep ecology can be a revolutionary metaphysics, epistemology, cosmology, and environmental ethics (Devall, 2005).

It must be recognized that deep ecology, which calls for a radical egalitarianism political implementation, would require agreements that would be difficult to reach; it is difficult to break down into concrete, short-term steps in practice. However, any concept fully endorsed by all parties must surely be bypassing the heart of the conflict (Campbell, 1996). Unlike the idea of sustainability, which lends itself nicely to meeting on the common ground of competing values systems, deep ecology will be particularly effective if it acts as a lightning rod to focus conflicting economic, social, and environmental interests. The more it stirs up conflicts and sharpens the debate, the more effective it will be (Campbell, 1996). In the point of view of this researcher, this theory is operational and it must move well beyond environmental education and moral suasion; rather, it should make use of all the political tools at their disposal. Deep ecology brings a sense of urgency and outrage to the policy realm (Ernst, 2009). Deep ecology, if redefined and incorporated into a broader understanding of political conflicts, can become a powerful and useful organizing principle for planning.

4.3.2 How deep ecology will affect urban planning

Planners deal with multiple objectives, which are demonstrated in Figure 3. Planners stand at every moment at the center of the polygon. In an ideal world, planners could achieve a balance among the different objectives. In practice, however, professional and fiscal constraints drastically limit the leeway of most planners. Planners confront deep-seated conflicts among economic, social, and environmental interests that cannot be wished away through admittedly appealing images of a community in harmony with nature (Campbell, 1996). In most cases there are no common interests and planners will invariably create a development scheme that harms some interests.

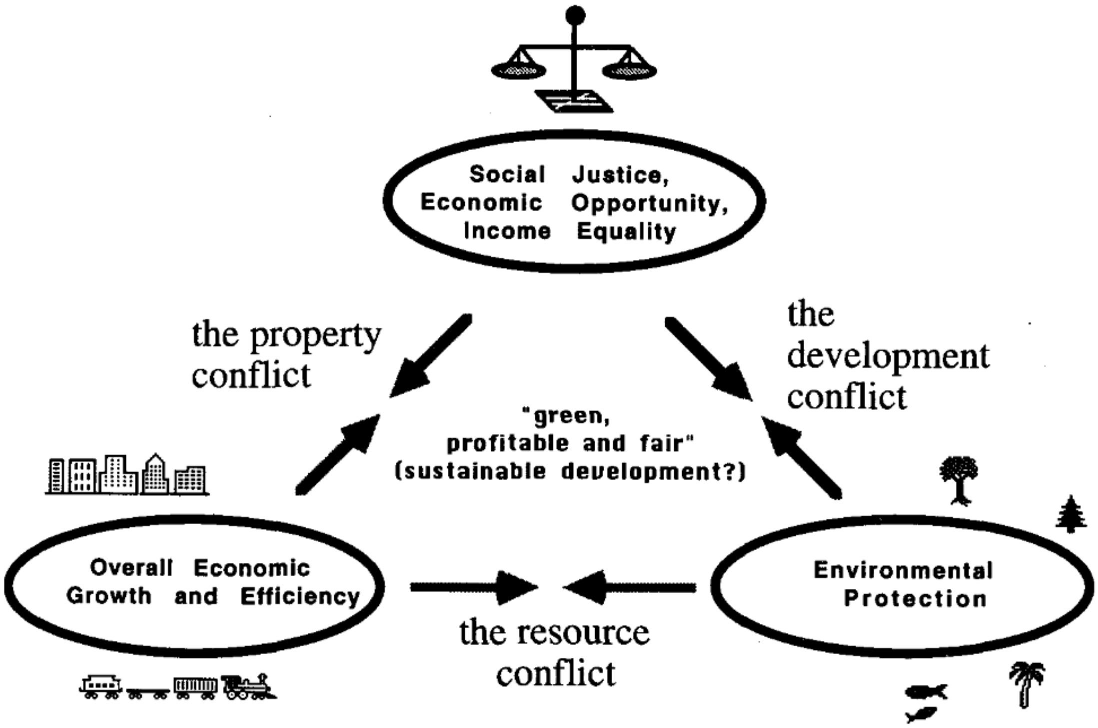

Figure 4.2: The Conflicting Goals of Urban Planning. This figure shows the multiple-dimensional conflicts in contemporary environmental disputes for planners. Deep ecology aims to increasing the weight on the environmental dimension in such conflicts Taken from: Campbell, 1996, p. 298.

The social dimension of environmental conflicts is found in the development conflict (Campbell, 1996). In a healthy environment, all competing actors complement one another, while each fulfills its niche in the overall system. When each group plays its role, the policy process moves forward; incrementally, but at a steady pace (Ernst, 2009). Deep ecological doctrines prioritize equality for all species, which means human and other species deserve equal rights and opportunities. Introducing deep ecology into urban planning does not aim to realizing extreme species egalitarianism, instead, it sets an objective for development: during the process of the social construction of nature, planners are required to try their best to avoid the materialistic pitfall of arrogantly denying any aspects of nature beyond the labor theory of value (Campbell, 1996). Deep ecology gives a reason to planners to give serious consideration to the utilitarian principle, according to which one must not only look out for man's best interests, but also, more generally, one should try to both diminish the total suffering in the world as much as possible and increase the quantity of well-being (Ferry, 1995).

Anthropocentrism is shown to be problematic because it values human, usually, economic factors above environmental ones. This problem is at the core of the deep ecology critique. Under the anthropocentric paradigm, people pay attention to environmental problems by seeing themselves as victims whose health was endangered. The selflessness derived from deep ecology advocates for fairness between humans and wildlife. This expansion of equity to include other species creates the possibility for contradictions. However, as Campbell (1996) stated, the choice between an anthropocentric or an ecocentric world view is a false one. We are all unavoidably anthropocentric; the question is which values and priorities we will apply to the natural and the social world around us. Singer (cited in Ferry, 1995) rightfully insisted that "the principle of equality of all life beings is not a description of an alleged actual equality among humans, it is a prescription of how we should treat other beings" (Ferry, 1995, p. 33). Introducing deep ecology to urban planning does not aim to realize a radical egalitarianism, but to move the discipline toward wildlife-friendly practices in an evolutionary progression. This ideology helps planners place more weight on ecological benefits when using the traditional cost–benefit model to make a decision. Almost every planner holds dual world views. Their different positions on conceptions of nature, uses of nature, and how they incorporate nature into their value systems determine where they will stand in the frequent clashes between humans and nature. The introduction of deep ecology urges planners to slide nearer to the ecological pole along the economic–ecological spectrum. The dialectic paradigm avoids a dichotomous, black-and-white view of urban planning.

People's definitions of nature are shaped by their socialization. We are all unavoidably anthropocentric; the question is which values and priorities we will apply to the natural and the social world around us (Campbell, 1996). Deep ecology offers individual planners one more option. They do not have to stand outside the conflict or be a neutral mediator; instead, they can identify their specific loyalties and roles in these conflicts. They can jump into the fray and promote their own visions of ecological conservation.

Applied in urban planning, deep ecology ensures that nature is treated as a formidable preexisting condition that cannot be easily altered. As Capra (1975) stated, there is wisdom in the stability of natural process". Respect for the capacity of nature to reproduce the life-support systems of the Earth should be internalized into the planning process (Haila, 1999). A city always poses a threat to nature. The process of urban planning aims to minimize this threat, and urban design should work with not against nature (Capra, 1975; Devall, 2005). Urban space should not be planned as an economic space of highways, market areas, and commuter zones, but as an ecological space of greenways, river basins, and ecological niches (Campbell, 1996). For example, the low-impact design model, which is affected by deep ecology, suggests that support systems (food production, fresh water, and wastewater treatment) are designed to work with the patterns and processes of natural systems, with a focus on an integrated approach (Newman and Jennings, 2008). There are also other theories like eco-city, green infrastructure, or megacity that all are supported by this ideology.

Deep ecology may change significantly the way planners deal with problems involving native wildlife and plants. Newman and Jennings (2008) insisted that only deep ecology is involved in the decision-making process; with consideration of all living organisms like humans, animals, plants or microbes, and nonliving components including materials or energy flows interacting as in any other ecosystem, the solutions can be identified (Newman and Jennings, 2008; Vichi *et al*., 2007). Today, this ideology has not been realized as principles or strategies. However, to some extent it liberates ecological consciousness and makes a principle change, even though sometimes compromise is inevitable.

Under deep ecology, life is considered as more than an economic term or a statistic. Any existing life form stands as a unique component of the world and makes an essential contribution to the diversity of nature. Other creatures should not be treated as subordinates of humans, but humans should take responsibility for their well-being. Even though in most cases priority is given to economic growth, a tree should not be cut down, or a raccoon excluded from its original home, without deliberate consideration. The object of planning is not to maximize human benefits at any price, but to seek a balance between human and other life. When dealing with human–wildlife conflicts, planners should attend to the interactions between humans and wildlife and understand the myriad processes that support life. A renewed view of the relationship between humans and wildlife is at the center of this new paradigm. Widespread deployment of this innovative tactic may change the way humans plan and design, and with this, change people's lifestyle.

Ecology has a closer relationship with this concept. The scientific discipline of ecology is one of the five sources[10] for the deep ecology movement. As early as the 1970s, some ecologists, such as Donald Worster, Murdoch, and Connell, expressed a similar opinion that ecology was not a science that was open to co-operation with engineers who want to enhance, manage, or preserve the biosphere, but a knowledge body for conservationists and members of the public to sustain the original harmony (Worster, 1994). The introduction of ecological knowledge is necessary to set up this new paradigm in planning. A deep ecological position helps planners better interpret research results in natural science.

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[10] The other four sources presented by Devall (1980) are found in the flux of Eastern spiritual traditions into the West, which began in the 1950s with the writings of such people as Alan Watts and Daisetsu Suzuki; the re-evaluation of Native Americans during the 1960s and 1970s; the "minority tradition" of Western religious and philosophical traditions; and artists who have tried to maintain a sense of place in their work such as Ansel Adams, Morris Graves, and Larry Gray.

4.3.3 Deep ecology in WVC mitigation

Guided by anthropocentric ideologies, including light green theories, the top priority in WVC mitigation is to reduce human injuries and economic damage. Economic valuation of WVC is anchored in an economic perspective, based on the impacts of wildlife loss on human welfare. Economic valuation of wildlife loss leads to monetary indicators, regarded as a common unit for comparison and ranking of alternative WVC mitigation measures (Nunes and van den Bergh, 2001), There are some intrinsic flaws in the economic valuation approach, appearing whenever it is applied to any complex environmental problem (Ackerman and Heinzerling, 2002). For wildlife, mitigation measures will not be implemented until the population loss in WVC significantly impacts the total population. There is a long-existing method to identify the alarm threshold for WVC, which was stated by Dunthorn and Errington (1964) as: "the number of a given species killed by traffic within a particular area has little intrinsic value…the proportion of the immediate population so killed has more meaning" (p. 180). Consequently, there is a high threshold to implement WVC mitigation measures.

Wildlife is not a commodity and does not have a price. Dunthorn and Errington (1964) conclude by considering the implications of deep ecology for WVC mitigation. The introduction of this ideology extended the environmental agenda, which was limited and narrowly focused. Under the new paradigm, environmental politics and policies would vary in a) the relative political salience of environmental issues over time; b) the willingness of planners to adopt innovative regulatory policies and programs; and c) the emphasis on protecting nature for its own sake (Vogel, 2001).

Traditionally, institutional decision making in modern human societies assumes that all relevant dimensions, including natural resources and wildlife, can be assessed in terms of economic value and, hence, creates markets for everything (Kamppinen and Walls, 1999). Deep ecology suggests that our first ecological priority must be preserving “all species, sub-species, varieties, communities, and ecosystems that we possibly can” (Sessions, 2014, p. 112). Under deep ecology, wildlife is set as a boundary condition for decision making. The idea of boundary conditions in decision making is that things that are too valuable or even beyond valuation are set aside, and decisions are made in such a way that these conditions are not violated (Rescher, 1982). From the perspective of deep ecology, wildlife would be regarded as non-negotiable and not for sale, and that should guarantee preservation (Kamppinen and Walls, 1999). In this scenario, the objective of WVC mitigation strategy is not to reduce economic loss, or maintain population size, but rather to eradicate WVC to save life.

Deep ecology serves as a strong motivation for planning departments to fight against WVC. Introducing deep ecology to urban planning provides a sound reason for the planning department to enact more ambitious and stricter regulatory standards to protect the welfare of animals and to end cruelty to them, and it will change the view of the planning department of WVC mitigation as an expensive burden to maintain. There is evidence showing that WVC mitigation regulations are enacted more strictly, and WVC mitigation infrastructures are implemented more frequently in countries labeled as deep ecological, such as Australia, Scandinavian nations, the United States, and Canada[11] (Vogel, 2001).

Through emphasizing the value of every individual life, not only of humans but also of wildlife, the strategy framework sets animals as the clients of urban planning and the users of WVC-mitigation infrastructure design. According to the principles of UCD, study of a species' basic biology and its behavioral characteristics is an important stepping stone in seeking solutions to WVCs. This research uses a methodology that embraces both the subjectivity of humanity and the objectivity of ecological knowledge. This can come about, not by dismissing either humanity or science, but by first detaching them from the obsolete ideological matrix that limited their field of interaction. Deep ecology is based on the cognitive model that wildlife is intrinsically valuable, it ensures that ecological considerations have direct input during the planning process. Urban planners should increase their motivation to learn when they are solving these interdisciplinary problems. The ability of learning can turn into a strategic advantage in practice. For WVC, urban planners should be well informed about wildlife movement issues and basic biological knowledge which ensures an improved performance and a more effective outcome.

Deep ecology emphasizes that an effective WVC mitigation strategy should rely on a form of "information-based" regulation, the essence of which is to require

[11] According to Vogel, "in dark green countries, environmental politics and policies are more likely to express an environmental ethic-one which encompasses but goes beyond domestic health, safety and amenity concerns. By contrast, in light green countries, environmental politics and policies tend to be more instrumental; they are more lightly to represent responses to clearly defined threats to domestic public health." (Vogel, 2001. p. 6).

the best available methods for controlling WVC. Deep ecology places the effectiveness rather than economic efficiency as the top priority of a mitigation plan. This ideology should best be regarded as complementary, non-quantitative methods for assessment of WVC mitigation. In what follows, a strategy framework will be presented. The strategy gives a clear-cut idea for how deep ecology should affect strategy.

Chapter 5

MITIGATION STRATEGY FRAMEWORK

This chapter presents a WVC mitigation strategy framework. The framework has been developed under the guidance of the new paradigm principles presented in Chapter 4. The framework uses ecological information to develop effective local WVC mitigation measures and describe how to implement them on local existing roads. The framework includes step-to-step guidance to develop species-specific mitigation strategies.

This mitigation strategy framework can be used by government agencies, planners, and designers to develop mitigation strategies for local affected species.

An eco-centered ideology requires a change to the traditional conservation approach and to the way work is designed, delivered, and evaluated. WVC mitigation strategy planning develops options and actions to enhance survival for, and reduce threats to, the target species. The development of this mitigation framework is based on principles of urban planning, as well as well-established ecological and biological knowledge. The framework is designed to work out details on mitigation strategy and to narrow the gap between theory and practice.

To maximize effectiveness, the mitigation strategy is designed with two characteristics. The first is that it is species specific. In practice, the strategy may be modified to accommodate multiple species due to overlapping WVC hotspots and financial considerations. In addition, the framework is developed in an ideal scenario to obtain better accordance with the targets, and circumstances for the wildlife are optimized without emphasizing realistic spatial and economic limits. In this scenario, the maximum positive wildlife-directed efforts were taken.

The second characteristic of the designed framework is it explores the possibility of reducing WVC to zero. This standard is also should be included in the assessment process. The planning department is encouraged to pursue those measures that will achieve this objective. Even if this standard is not adopted in practice, it forces the planning department to consider this option.

5.1 From Human-centered to Wildlife-centered Therapy

There are two premises of this framework: first, humans have selfless moral considerations toward non-human entities. In real life, people are unavoidably anthropocentric, seeing the world from a human perspective. Judgements about what is valuable for its own sake begin from the understanding and experience of what is valuable to the individual (Campbell, 1996; Hughes, 2000). This framework is constructed in a scenario in which human privilege diminishes. This eco-centric view ensures that the involved wildlife are given as much attention as possible.

Second, in order to avoid favoritism, all species are treated equally in this framework. In reality, some creatures are more valuable than others. Normally species with higher degrees of self-awareness and greater capacities for meaningful relationships with others get more attention. For WVC, species that have a higher possibility for causing human and vehicle damage are given more attention and are addressed more frequently. For example, a survey found that 1,600 billion insects are killed on roads every year in the Netherlands (Messenger, 2010). In spite of this astonishing number, little has been done to prevent or reduce these little deaths, because the insects are too small to lead to any human or economic loss. In practice, admittedly, it is hard for us to treat an insect as serious as a large-size mammal, this framework insists that at least in the *research* on WVC mitigation, the same time and attention should be given to all species. This framework does not consider species differences. Instead, it recognizes that all beings have a similar right to life, and mere membership in the human biological species cannot be a morally relevant criterion for this right (White, 2009).

This framework takes a step from a human-centered toward an eco-centered ideology. Developed under a new paradigm, the framework has the following characteristics, which are distinctive from previous framework characteristics:

- It guarantees that WVC mitigation efforts receive more attention and resources. Currently the mainstream attitude toward WVC mitigation is that the more damage it has caused to human, the more attention it can get. The spiritual transformation in the new paradigm makes the wildlife killed in WVC not just a number, or a sign of local abundance, or a fact to use to speculate about financial damage or human injuries. Each WVC victim means that individuals with the capacity for experiencing pleasure or pain have gone. From this perspective, the purpose of WVC mitigation is to avoid suffering and save lives. This reasoning is sound enough to require more efforts from scientific research and in practice.

- It guarantees that all victim species can get attention. Currently, big and medium body size species and species on the IUCN Red List are given more attention and mitigation efforts. From a deep ecology perspective, all life has the same intrinsic value and should have equal opportunities for salvation.
- It lowers the threshold for initiating a WVC mitigation strategy. Currently the two determining factors in starting a mitigation strategy are (1) whether WVCs have led to high economic losses, and (2) whether WVCs negatively affect local wildlife populations, especially when the affected species are listed as endangered. From the perspective of deep ecology, mitigation measures are taken not only to reduce economic loss but also to prevent suffering and death. Mitigation needs to be done even if wildlife deaths in WVCs are not enough to influence the local population. The motivation to mitigate WVC is significantly enhanced in this framework.
- It guarantees that more resources will be distributed to WVC mitigation strategy implementation. Financial and human resources considerations

are main restrictions to developing mitigation strategies. WVC mitigation is given a low priority on urban planning department work schedules.

- From the perspective of deep ecology, it is not appropriate to assign an economic value to life. Admittedly, in practice, it is impossible for us to save a squirrel at any price. As addressed in Chapter 4, this ideology offers a value system rather than asserted facts. The deep ecologist Peter Singer (1990) asserted that "as long as we remember that we should give the same respect to the lives of animals as we give to the lives of those humans at a similar mental level, we shall not go far wrong" (p. 21).
- It guarantees more effective WVC mitigation measures will be explored. Deep ecology, which respects and pays attention to non-human entities, supports an animal-centered design method. This method changes anthropocentric design attributes and placement strategies, and further maximizes ecological returns on investments in WVC mitigation. For example, biologist Hara Woltz and her colleagues created a series of behavioral choice arenas to identify particular preferences that might stimulate amphibians to use road-crossing structures (Woltz *et al.*, 2008). Their experiments make a significant contribution to the design of more effective crossing structures.

5.2 Organizational Structure

WVC mitigation is an interdisciplinary topic that needs a network of partners working toward the same goal. The network comprises diverse governmental, academic, and nongovernmental organizations as well as the public. The recommended organizational structure of a WVC mitigation committee is described in Figure 5.1:

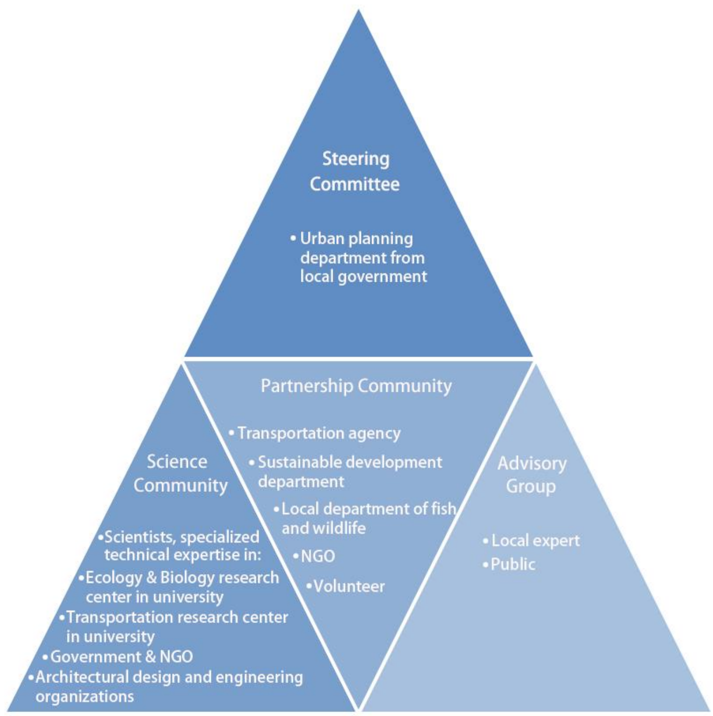

Figure 5.1: Organizational Structure
Source: Prepared by the author.

The main roles and functions of the four organizations are as follows:

Steering Committee: The steering committee is composed of staff from the local urban planning department. The committee directs a project from start to completion. The steering committee is central to the development and implementation of a specific WVC mitigation strategy. Its role is to ensure the achievement of project outcomes. This work may include tasks such as:

- Providing input about the development of the strategy
- Setting and approving the vision, goals, and priorities of the strategy, and defining detailed steps for further implementation
- Staff direction
- Defining and helping to achieve the outcomes
- Identifying the priorities in the project—where the most energy of human and financial resources should be directed
- Identifying potential risks in case the mitigation measures do not work
- Making a timeline to monitor the quality of the project after it is implemented

Science Community: WVC mitigation needs professional knowledge of planning, ecology, road safety, and architecture. The science community is organized on an expert-based model and formed by members from various disciplines who can serve as the most readily available source of knowledge. The responsibilities of the science community include the following:

- Developing and providing for specific science needs
- Participating in committees or in work groups

- Helping to predict risks of the strategy

Advisory Group: These local experts are individuals with a holistic understanding of the local ecological environment or a specific local species. They have above-average knowledge. This experience-based knowledge of local experts primarily supplies information on species, their distributions, and migration activities. Some local experts may focus on the processes that drive change in ecosystem. If knowledge about specific resources or processes is required then it is important to select and work with such local experts (Chalmers and Fabricius, 2007). The public plays an important role in reporting WVC occurrences, which help to define WVC hotspots and help in the monitoring process after the strategy is implemented. Only by working with local experts and residents on more practical strategies can the problem of WVCs be successfully addressed and resolved.

The advisory group can add value to the science community. Its responsibilities are as follows:

- Coordinating science needs and strategy development
- Collecting data through a WVC reporting system
- Participating in the project funding process
- Helping to monitor the project

Partnership Community: The development and implementation of WVC mitigation strategies needs cooperation from various organization, both governmental and nongovernmental. The partnership community cooperates with the steering community to achieve the WVC mitigation goal. The responsibilities of the partnership community are as follows:

- Set priorities of the mitigation strategy
- Support strategy implementation

5.3 WVC Mitigation Strategy Framework

This WVC mitigation strategy framework has two distinguishing characteristics that are not occupied by prior strategies. First, it emphasizes the leading role of government in WVC mitigation strategy development; second, it stresses the importance of ecological information during strategy development. The development process is shown in Figure 5.2.

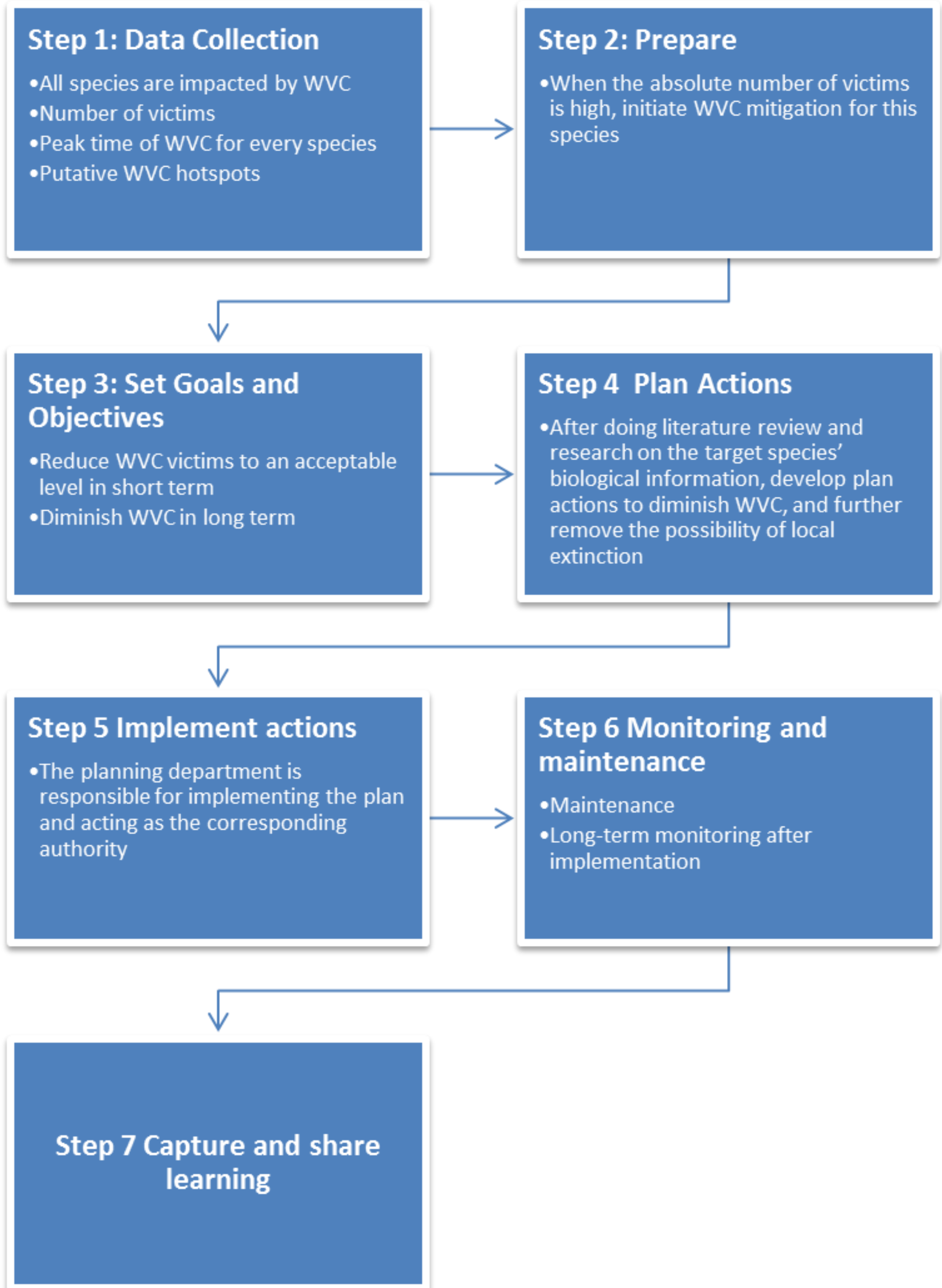

Figure 2.2: Steps to Develop a Mitigation Strategy
Source: Prepared by the author.

5.3.1 Data collection

The data needed for WVC mitigation strategy development include: Species—all the species affected by WVC; number—how many deaths have been reported in a year; season—The time of peak WVC occurrences; although it is difficult to record the exact time, in most cases the month in which the WVC occurs can be identified; location—where the WVC occurs or where the dead body is found. There are two sub-steps to data collection, a public reporting system and a field survey:

- Build a public reporting system[12]. Crowd-sourcing data from volunteers are an important source for fast and large-scale WVC data collection. This system will be especially useful if it keeps working for years. Anyone, mainly cyclists and pedestrians, but even people in cars, can report a sighting. A local online or telephone reporting system administered by the urban planning department for notification of a WVC occurrence should be established. The reporting system should be established together with a roadkill salvage system. The following factors should be included in the public reporting system:

    - Species
        - Name. For an online reporting system, pictures of different species can be presented for users to choose. Figure 5.3 gives

[12] Currently there are no large-scale WVC reporting systems in the world, and no standardized protocols. But some local WVC reporting systems have already been established (McLendon, 2012).

an example from the Roadkill and Wildlife Salvage reporting system under the Idaho Department of Fish and Game (2015), U.S.A.

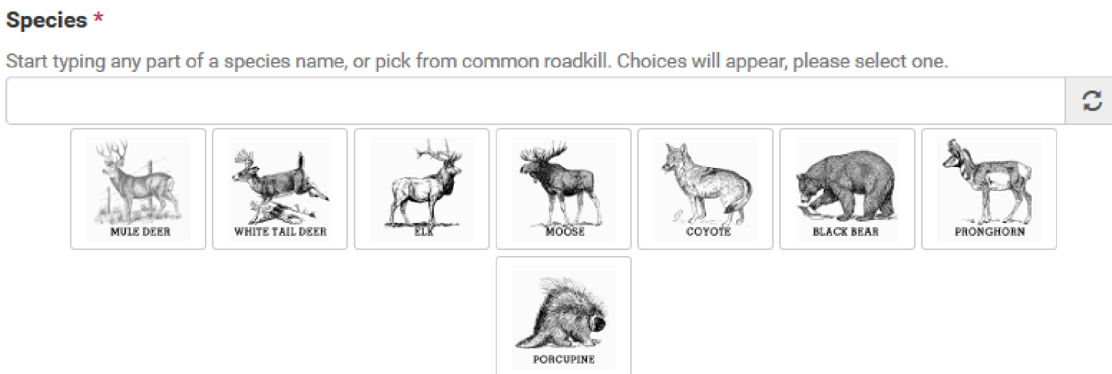

Figure 5.3: A Species Report that Supplies Sketches of Animals to Help Users Define the Victim Species
Photo Source: https://idfg.idaho.gov/species/roadkill/add.

- How confident the user is about the species name. A number of options are given for users to choose—from *I'm absolutely certain* to *Please help me identify*.
- Species account, either by a description, a photograph, or a video. Uploading a photo is highly recommended.

- Where

  The location where the WVC victim is found. The website should offer diverse ways for users to provide the location: e.g., click a location on an electronic map; select a highway and enter a mile marker or mile segment; use GPS coordinates; use modern web browsers and mobile devices to locate the WVC; or describe the surrounding environment.

- When

  Record the date and time when they find the WVC victim.

- Conduct a field survey. A Geographic Information System (GIS) computer model can be used to organize collected data. The model should capture, manipulate, display, and combine spatial information such as species distribution, ecological corridors, attractive elements for the target species, and existing roads. Putative WVC hotspots are intersections of roads with species' movement paths, and road segments running through important species habitat. Results from the public reporting system should also be used to define potential hotspots.
  - The first purpose of the field survey is to supply more accurate information about important ecological characteristics, especially those that cannot be detected on satellite maps.
  - The second purpose of the field survey is to ensure the validity of putative WVC hotspots through road survey. Road survey should be conducted regularly by professionals on foot, by bicycle, or by car to search for WVC victims. Foot or bicycle patrolling is recommended for all species, while car patrolling is only suggested for large animals. There is evidence that a walking survey can record 5.5 times more WVC victims than driving in a car, even at

speeds less than 40 km/h. Foot patrolling also can record the taxa of victims that are otherwise overlooked (Puky, 2005). The timing of a road survey should correspond to the peak season for WVCs with the target species. Patrolling will ultimately determine and prioritize WVC hotspots.

Outcome: Researchers learn which species are involved in WVCs, the number of victims, the peak time (including seasonal peak and daily peak) of WVC occurrence and the putative WVC hotspots. Through long-term data collection, accurate spatial patterns of target species road mortality can be determined. GIS is an important tool in developing species-specific mitigation measures.

Species specialists should be brought in as early as possible in the planning and design of mitigation measures to ensure the measures will function as intended.

5.3.2 Prepare

Once the steering committee identifies the impact of WVC on a specific species and determines to develop a mitigation strategy. A "heads down" attitude is recommended to ensure the execution of the mitigation strategy to be operated on "cruise control" under an eco-centric ideology.

- Set up the project. The number of deaths and the behavioral characteristics of the target species determine what kind of mitigation measure should be taken. The planning department should start the set up.

- Assemble an appropriate team based on the organizational structure presented in section 5.2. Scientists and local experts with professional knowledge of the target species should be included on the team.

Outcome: this step initiates the WVC mitigation strategy.

5.3.3 Set goals and objectives

Goals and objectives help the steering committee measure the extent to which the aims are being achieved. This step includes the following:

- Develop a qualitative description of the desired future state of the target species.
- Define the agreed-upon vision in operational terms to help direct implementation, including budget, deadlines, and goals.
- Specify indicators by which success of the strategy can be evaluated. The most direct result is reduced wildlife deaths. With the help of a public reporting system, it is easy to evaluate the success of the implemented mitigation measures.

Outcome**:** both long-term vision and short-term motivation are set for the strategy. It helps the steering committee to organize time and resources so that they can maximize the effectiveness of the strategy.

5.3.4 Plan actions

This step involves determining what needs to be done to achieve the desired outcomes, as well as how outcomes will be monitored. The sub-steps including:

- Identify possible actions to achieve specific objectives, then describe which actions could be taken and when.
    - Literature review. Mitigation efforts have been undertaken in many places. These activities are especially active in European countries such as Germany, England, Norway, Finland and the Netherlands. Evaluation of the effectiveness of these mitigation projects or descriptions of their experiences may be found in news, governmental reports, and research papers. Evaluation is essential to ensure that successful measures are widely adopted, and unsuccessful ones are not repeated (Soanes *et al.*, 2013). Table 5.1 gives a general review on the most widely-implemented mitigation measures.

Table 5.1 Common WVC Mitigation Measures

Measures	Example	Cost	Target species	Effectiveness	Approach
Warning Signs	 (Photo source: http://www.vetstreet.com)	Low. Around US$500 (Safety Signs, 2016)	All species	Feasible when implemented on accurate WVC hotspots	Changing Drivers' behavior

<table>
<tr><th>Measures</th><th>Example</th><th>Cost</th><th>Target species</th><th>Effectiveness</th><th>Approach</th></tr>
<tr><td>Speed Limit</td><td>

(Photo source: http://canmua.net)</td><td>Low. Around $500 (Safety Signs, 2016)</td><td>All species</td><td></td><td></td></tr>
<tr><td>Traffic Calming</td><td>
(Photo source: http://www.autoevolution.com)</td><td>Medium</td><td>All species</td><td>Can help to reduce WVC mortality of individual animals dramatically</td><td></td></tr>
<tr><td>Public Awareness Programs</td><td></td><td>Medium</td><td>All species</td><td></td><td></td></tr>
<tr><td>Closure or Removal of Specific Road Segments</td><td>

(Photo source: http://flickrhivemind.net)</td><td>Medium</td><td>All species</td><td>The most effective WVC mitigation measure; however, it can be used in only a few situations</td><td></td></tr>
<tr><td>Wildlife Reflector</td><td>
(Photo source: http://balizamiento.com)</td><td>Medium</td><td>Animals with acute night vision</td><td></td><td></td></tr>
</table>

Measures	Example	Cost	Target species	Effectiveness	Approach
Animal Detection System	 (Photo source: http://www.nytimes.com)	Medium. Around US$300,000; the cost can drop to US$70,000 to US$80,000 if widely adopted (*The New York Times*, 2013).	Medium to large mammals		
Animal Crossing	 (Photo source: http://theg6group.com/road.html)  (Photo source: http://www.wilderutopia.com)	Medium to high. Over-road crossing with fences can cost upward of US$2.5–8 million apiece; under-road tunnels cost less—as little as US$10,000 (Gaskill, 2013; *The New York Times*, 2013).	All species	High	Changing animals' behavior
Fencing	 Source: http://www.wilderutopia.com)	High		High	

- Research target species biological information and typical behavior. This ecocentric approach encompasses a shift to more strategic, accountable, and adaptive actions driven by science. Every species has specific behavioral patterns and habitat preferences, and mitigation measures must be developed with a species-specific approach. For example, an eight-foot fence is high enough for most medium-sized mammals, but a moose can jump over it and become trapped on a highway (*The New York Times*, 2013). Biological information that may benefit mitigation measure development is listed in Table 5.2.

Table 5.2 Ecological Information that May Contribute to WVC Mitigation

Research Scope	Type	How Does It Help?
WVC Patterns	Reaction of the animal to roads and traffic: crossings, stopping or staying on the road?	Determine the mitigation approach: to keep animals off roads or facilitate crossing
	Peak time/season of WVC occurrence	Determine the implementation periods for mitigation measures and when maintenance starts.
	Characteristics of WVC hotspots: road scheme, and adjacent landscape of a specific road segment, and so on.	• Help to define local hotspots • Modify the physical environment of WVC hotspots to remove factors that are attractive to wildlife
Habitat Characteristics	Variables such as humidity, temperature, light intensity, or spatial relationships	• Determine which type of crossing infrastructure should be used • Construct a similar environment to the natural habitat around or on the crossing infrastructure
	Vegetation cover—species, height, richness, etc.	• Remove plantings along roadside to avoid attracting animals • Place native plants near the crossing entrance and on the crossing to encourage use.
	Hydrological characteristics—water body size and depth; phosphorous and nitrogen contents	Profound effects on some reptiles and amphibians

Species-typical Behavioral Characteristics	Locomotion pattern	Determines speed limits and crossing infrastructure design
	Natural defensive behavior	Predicts reactions to oncoming traffic
	Body size	Determines the size of crossing infrastructure
	Timing of daily activities	Determines the type of crossing infrastructure and timing of traffic calming implementation
	Foraging pattern	Suggests measures to prevent roads or roadsides from becoming foraging sites
	Behavioral modification in response to roads	Gives more information to the design of mitigation measures
Life Cycle	Breeding season	• Animals tend to be more active in breeding season, which implies higher WVC • Juveniles are always especially fragile to WVC. Strict measures need to be taken for WVC mitigation when juveniles are involved.
	Seasonal migration pattern	Frequent road crossing is possible in migration season
	Hibernation	• No mitigation measure needs to be taken during hibernation periods • Maintenance of mitigation measures should start before the hibernation period ends.

- Predict outcomes. Assessing the likely impact of alternative courses of action based on the local context. It is necessary to make comprehensive assessment of an integral part of mitigation practice. It avoids the wasteful and ineffective use of resources.

  The traditional cost-benefit approach needs to be challenged under the deep ecology ideology. Deep ecology insists that life doesn’t come with a price tag. The outcome should be measured mainly by its effectiveness rather than its cost.

- Decide actions and strategies. Selecting the final strategy from the available alternatives.

Outcome: The mitigation measures are finally determined and ready for being implemented.

5.3.5 Implement actions

Now the planning work is put into practice through the development and implementation of specific work plans, while ensuring sufficient resources and capacity.

- Develop work plans, timelines, and budgets. The planning department is responsible for implementing the plan and acting as the corresponding authority. Define what activities are required, by whom, when, and how. Involvement by the transportation department, environmental organizations, volunteers, and sometimes even construction companies is expected in the process.
- Implement the strategy. Promote conditions under which implementation is likely to occur.

Outcome: The process of executing mitigation actions.

5.3.6 Maintenance and monitoring

- Maintenance. Most mitigation measures need to be maintained on a regular basis. For example, entrances of animal crossings need to be cleaned of snow to make them visible; animal reflectors need to be cleaned regularly to stay reflective; and fences need to be checked for holes.

- Monitoring outcomes. Monitoring includes tracking WVC occurrences after a mitigation strategy is implemented, identifying new threats, and evaluating the effectiveness of the mitigation process throughout the project. The effects of WVC mitigation measures will reveal themselves slowly, thus monitoring should be long term.

  Various monitoring techniques have been used to document wildlife use of structures (Forman, 2000), such as visual observations, tracking beds, passive data-logging radio receiver systems, cameras and counters, telemetry, or trapping and tracking studies. Visual observations, cameras and counters, and tracking studies are used to determine use by medium and large species, trapping are used for small mammals and herpetofauna (Andrews *et al*., 2011; Tonjes and Smith, 2011). A combination of monitoring techniques across a variety of taxa is recommended to evaluate crossing use (Bellis, 2008). In addition, public involvement with large-scale monitoring programs is recommended.

  A before-and-after comparison is the main monitoring approach to estimate the efficacy of implemented mitigation measures. The monitoring process, in conjunction with pre-implementation surveys, is necessary to assess the effectiveness of the mitigation strategy (Abbot *et al.*, 2015). If the situation has not changed sufficiently, the current mitigation strategy is deemed ineffective and should be improved (MITRE, 2013).

Outcome: This crucial stage after WVC mitigation strategy implementation evaluates efficacy and ensures that they hold up well.

5.3.7 Capture and share learning

This step involves disseminating results to key external and internal audiences to promote learning. The experience supplies a template to recognize and organize the common steps in practice, and to examine actual conflicts that may possibly happen.

Outcome: The results of a mitigation strategy are summarized and disseminated, and then the information is published in public media, government reports, or research journals to guide practitioners and inform future planning efforts.

Chapter 6

SPECIES-SPECIFIC MITIGATION STRATEGIES FOR FOUR SPECIES

This chapter is an application of step 4 in the framework developed in Chapter 5, plan actions: developing a mitigation strategy based on the target species' ecological and biological information. This chapter defines four frequent WVC victim species, explores their behavioral characteristics, and develops appropriate WVC mitigation measures based on their species-specifics. The strategies contain detailed information on preparation, development, and implementation. If a crossing facility is presented as an appropriate mitigation measure, detailed crossing structure models are developed with the aid of computer technology. Design details of scale, materials, shape, wildlife furniture, and so on are all presented in the models.

Mammals, amphibians, reptiles, and birds are all common WVC victims. In different surveys on WVC victims each class demonstrates different percentages of victims, but normally they are all involved (Ashley and Robinson., 1996; Kioko *et al.*, 2015). Insects are definitely important victims too, but little information can be found in published literature, thus insects are not addressed in this paper. The four targeted species were selected because they are widespread and abundant, recognized as frequently involved in WVC based on published empirical information, and distinctive in movement patterns. The species are two mammals, the European badger (*Meles meles*) and eastern gray squirrel (*Sciurus carolinensis*); a bird, the house sparrow (*Passer domesticus*); and an amphibian, the northern leopard frog (*Lithobates pipiens*). Species-specific mitigation measures are developed based on established ecological and biological knowledge. The mitigation measures presented in this chapter are unproven, and further research is required before widespread implementation.

As addressed before, the most effective mitigation measures should be developed based on the species specifics. Due to being considered for one species, some contradictions may appear—a mitigation measure may be favorable for one species but harmful for another. These models that presented in this chapter will need to be modified to respond to local ecological environment. Planners should have comprehensive knowledge on local species, and their relationship with roads. Those measures that presented in the following strategies are designed only for the target species. When the presented measures may harmful for other species, they should be avoided.

6.1 European Badger (*Meles meles*)

6.1.1 Basic biology

M. meles has a stocky body with short robust limbs and a short tail. Adults weigh from 6.6 kg to 17 kg; average weight is 12 kg for males and 10.8 kg for females. Body lengths range from 56 cm to 90 cm. Tail length ranges from 11.5 cm to

20.2 cm (Pearce, 2011; Wang, 2011). Badgers can run or gallop at 25–30 km/h (16–19 mph) for short periods of time. Badgers are nocturnal. During summer they come out of their sett (den) before dusk, but emerge after dark in the rest of the year (Neal, 1986). *M. meles* lives in most of Europe, excluding northern Scandinavia, Iceland, Corsica, Sardinia, and Sicily. They can also be found in parts of Asia (Neal, 1986; Wildlife Online, 2014a). *M. meles* is classified as least concern on the IUCN Red List. Its densities have increased in Europe over the last decade because it is protected by law (IUCN, 2016a; Wang, 2011).

6.1.2 *M. meles* and WVC

Given the variation in number, size, and use of roads across the world it is perhaps not surprising that there is considerable variation in WVC mortality. However, WVC as a main reason for local population decline is frequently mentioned in scholarly papers and news (e.g., Dekker and Bekker, 2010; Lankester *et al.*, 1991; Neal, 1986; Royal Society for the Prevention of Cruelty to Animals [RSPCA], 1994; Vink, 2008; Wildlife Online, 2010). Hitting a badger, which may reach up to 17 kg in weight, or attempts at avoidance, can cause serious accidents and endanger human life (RSPCA, 1994). The characteristics of the occurrence of *M. meles* WVC are:

- There is a strong seasonal skew to badger road deaths. Most happen in spring. Also a few research note the seasonal peak is summer (Wildlife Online, 2014a).

- WVCs are inversely related to how busy the roads are. Single-lane roads cutting through countryside have the most WVC. High traffic loads may discourage badgers from attempting to cross (Wildlife Online, 2014a).
- Rural roads have more badger WVCs (Neal, 1986).

Currently used mitigation measures include the following: warning signs;, speed limits on road stretches with frequent *M. meles* WVCs; closure of certain stretches of roads during the night or in periods when badger activity is frequent (van Apeldoorn, 1998; Dekker and Bekker, 2010); badger reflectors mounted on small posts placed at certain points along roads to aim headlights at badgers as they cross, scaring them away from roads; and badger tunnels. Currently used badger tunnels are small and round, with a diameter of 40–50 cm, constructed of concrete or steel. Badgers are also adapted to existing infrastructures such as bridges and viaducts (Dekker and Bekker, 2010).

6.1.3 *M. meles* ecology and WVC mitigation suggestions

Most WVCs occur when *M. meles* is foraging. This species has high tolerance for human disturbance. *M. meles* does not avoid roads intentionally when they are foraging. So the species' reactions to roads and the characteristics of foraging activities, may offer important information for developing an appropriate WVC mitigation strategy (see Tables 6.1).

Table 6.1 *M. meles* Ecology and WVC Mitigation Suggestions

	Behavior	**WVC Mitigation Observations and Suggestions**
Reaction on Roads	*M. meles* always selects habitat near roads or other linear corridors (Dekker and Bekker, 2010).	This tendency makes badgers common victims of WVCs.
	If there is an ample supply of food, *M. meles* will tolerate a tremendous amount of upheaval (Pearce, 2011). *M. meles* has been observed crossing roads frequently (Hels and Buchwald, 2001).	*M. meles* does not avoid roads when it is foraging. WVC hotspots may occur when roads cross its home ranges.
Foraging pattern	Primary foraging areas include short grazed or mown grassland, golf courses, and broadleaved woodlands (>80% broadleaves); secondary foraging areas include arable land, rough grassland, scrub, and mixed woodland (Scottish Natural Heritage, 2015).	When preferred foraging areas are adjacent to roads, WVCs are a possibility.
	M. *meles* is omnivore. Its primary diet consists of terrestrial worms, insects, reptiles, carrion, etc. Plant foods are roots and tubers, seeds, grains, nuts and fruit, and fungus (Wang, 2011). Worm-rich soil is attractive to *M. meles.*	Plant vegetation that does not produce grains, nuts, or fruit, and remove fungus alongside roads to make road segments less attractive to *M. meles.*

	M. meles follows the same track to important foraging and feeding areas with rich resources, even when weeks earlier the tracks were ploughed in and apparently destroyed. The path system near a permanently occupied sett changes very little over years. Neal (1986) observed a *M. meles* path system that hardly changed over 30 years.	Make use of a path, artificial, natural, or a combination of both, to lead *M. meles* to crossing infrastructure.
	Familiar landmarks like a shrub, tree, ditch, or sudden twist can work as signposts for the *M. meles* to pinpoint an exact location (Neal, 1986).	Set landscape marks around the track to make the track easy to be found.
	Main tracks are 10–15 cm (4–6 in) in width, and do not turn or twist rapidly (Pearce, 2011). The main path may be followed for 300–400 m without difficulty (Neal, 1986).	An artificial path should be designed similar to a natural path. The length of the path can reach 200 m, but avoid sharp turns. The width should be 10–15 cm.
	M. meles knowledge of a path system is related to maze learning in other animals. If a *M. meles* is frightened near a sett, it rushes for home along one of these paths rather than choosing a possibly shorter route. The learning of a path system has survival value by enabling the animal to find the safety of the sett quickly	Design a network to funnel *M. meles* from its setts to other fields to avoid WVC.

	(Neal, 1986).	
Habitat Characteristics	*M. meles* is creature of habit, although there are exceptions (e.g., Pearce, 2011). Territory size depends on food quality and abundance as well as the amount of area suitable for excavating burrows (Wang, 2011). *M. meles* will extend their home territory when food availability is low.	During such periods more attention needs to be paid to WVC mitigation.
	Most *M. meles* live in countryside, urban residents were found to be of limited occurrence. The cities and towns that did report resident urban badgers are normally located in areas where badgers are numerous in the neighboring countryside (Harris, 1984).	Country roads may have more *M. meles* WVC occurrence than urban roads.
	Ideal *M. meles* habitat is undulating pastureland dotted with woods, hedgerows, and copses (Pearce, 2011).	Land patches with these characteristics needs to be marked in GIS.
	M. meles live in setts. Their den consists of one main sett and several outliers (Apps *et al*., 2002; Lankester *et al*., 1991).	Design the interior environment and the size of a crossing structure on a similar way to the tunnels of a natural sett.
	Frank Last, who is a *M. meles* expert, claims that *M. meles* is more	Ideally, *M. meles* paths could be designed for

	territorial during seasons when food resources are scarce, or in the early part of the year when the dominant boar is marking its territory (F. Last, Personal communication, June 18th, 2015). In addition, *M. meles* moves from one group to another to pair up for breeding, which prevents inbreeding. Neal (1986) noted that territories overlapped where population densities are high, and territory boundaries were not well defined. Under these situations, different groups may share the same path.	distinctive groups. Financial or physical restrictions often dictate a common path for *M. meles* groups that inhabit the same area. Define foraging areas for different groups during seasons when food resources are scarce because *M. meles* is more territorial at such times.
	M. meles prefers open habitats.	Clearance of a few square meters of vegetation to improve visibility of the entrance will improve their use of the crossing (Kinley and Newhouse, 2009).
	M. meles uses both natural and artificial tunnels. In the wild *M. meles* takes refuge from time to time in large, unused concrete drainage pipes, culverts, and other tunnel-shaped infrastructures.	An underground crossing is ideal for *M. meles*. Beyond intentionally designed *M. meles* tunnels, culverts, drainage pipes, and other existing infrastructures can be retrofitted or redesigned for use by *M. meles*.

	M. meles adapts to landscape change quickly and well (Pearce, 2011).	*M. meles* can be rerouted intentionally away from danger.
	M. meles normally does not travel too far from setts (Neal, 1986).	When the distance between a main sett and a roadway is longer than the maximum distance a *M. meles* will travel away from the sett, WVCs rarely occur.
Others	*M. meles* has short, but extremely strong, limbs and strong claws on its feet (Neal, 1986). These characteristics make the animal an efficient digger. They can move heavy materials in confined spaces (Leach, 2008).	*M. meles* can dig underneath fences used to prohibit them from crossing roadways. Fences need to be anchored in the ground with a right-angle bend in toward the field.
	M. meles climbs occasionally, up to 5 m on a sloping tree trunk. Vertical, slippery surfaces are impossible for them to climb (Pearce, 2011).	When fences are not tall enough, *M. meles* can climb over them. Common fence material like galvanized wire netting is easy for *M. meles* to climb. Slippery or solid fences can prevent *M. meles* from climbing. Exclusive *M. meles* fences need to be anchored in the ground, tall, slippery, and solid.
	When *M. meles* cannot see through	Solid wood or concrete

	an obstacle, it assumes it to be an impenetrable wall that they cannot go through (Pearce, 2011). It will look for a way to go around.	panels without gaps are appropriate materials for an exclusion fence.
	The *M. meles's* sense of smell is its most important sense (Neal, 1986). M. meles marks its territory with scent (either urine or a hormonal secretion from glands located either side of the anus and at the base of the tail) and dung pits (Wildlife Online, 2014a). *M. meles* continues using an old path after a landscape change, presumably because the scent lingers even thought all visual signs of the path are gone (Neal, 1986). *M. meles* uses dung pits dug beside a path, especially at some obvious landmark such as a hedgerow, a lane, or the edge of a wood, to mark its territory. These dung pit scent signals are always found a considerable distance away from a sett (Neal, 1986). A well-defined area can have many dung pits.	Scent-mark designed paths or crossings to encourage use by *M. meles*. Some soil from latrines or the spoil heap outside the sett entrance, both of which are impregnated with *M. meles* scent, can be used for this purpose. Each visiting animal will deposit more scent, and eventually the crossing will be accepted (Pearce, 2011). Put dung into man-made pits near landmarks beside constructed paths. For a newly constructed path, the density of artificial dung pits should be relatively high to make the scent obvious. Pits should be the same size as natural ones, preferably near or under a plant to help the scent last longer.

	M. meles is averse to strong sunlight. Strong light makes *M. meles* bury its head, shield its eyes with paws, or retreat into a dark corner. *M. meles* has good eyesight in low intensity light or at night. Anything that reflects any remaining light is often noticed at once (Neal, 1986).	Reflectors are useful for deterring *M. meles* from roads. Reflectors to direct headlights of oncoming traffic might serve as an alarm for *M. meles* attempting to cross the road. The light should last until the car has gone.
	M. meles has been observed using fallen trees as bridges to get across a stream or ravine (Neal, 1986).	A tree trunk can be used as a ledge in a culvert.

6.1.4 Suggestions for *M. meles* WVC mitigation strategy development

6.1.4.1 Data collection

Data retrieved from the public reporting system should be viewed with caution, because many *M. meles*–vehicle collisions may not be reported because they do not lead to severe crashes.

Field surveys may require repetition in spring and summer. In addition to counting *M. meles* deaths, a field survey develops a green network that includes the following information:

- All sett entrances, whether they are currently active or not, because *M. meles* move from one to another according to circumstances. They may reuse abandoned setts (Neal, 1986; Pearce, 2011; RSPCA, 1994).

- *M. meles* foraging areas, latrines, and paths. For areas with multiple resident groups, use bait marking technique to determine particular foraging areas for each group.
- The routes visited often by *M. meles* in traveling from setts to foraging areas should be located. This information is essential to determine the best location for construction of the crossing structure.

6.1.4.2 Plan action options

(1) Public awareness and education programs[13]

Such a program aims to improve understandings of road-related problems through general messages in the media, videos, brochures, posters, and bumper stickers (U.S. Department of Transportation and Federal Highway Administration, 2008). Successful public education programs have the potential to launch more complex mitigation projects (Puky, 2005). Local people as well as the general public should be involved in the education program. To ensure effectiveness of the education program, different strategies may be required for different groups, as summarized in Table 6.2**.**

[13] A public awareness and education program is recommended for all four species in this chapter. The common principles are stated here and will not be repeated for the following three species.

Table 6.2 Public Education Program
Source: Puky, 2005

Target Group	**Education**
Children	• Personal experience • Releasing their own abilities, and that they can have a positive influence
General public and Local people	• Road impacts on a specific species • Peak times and seasons of species activity • WVC hotspot locations • Locations of implemented WVC mitigation infrastructures
Decision-makers	• Concise text • List of completed actions • Review of implemented measures

Issues that should be highlighted in the public education program include the following:

- Important local areas for *M. meles* WVCs. Encourage drivers to slow down when driving through areas with *M. meles* crossing warning signs (RSPCA, 1994)
- Local short, grazed, or mown grassland that is known *M. meles* habitat
- WVC occurrences have a seasonal peak in spring to summer
- *M. meles* is nocturnal. The daily peak time of *M. meles* activities is from dusk to dawn

(2) *M. meles* crossing warning signs

Install traffic signage at WVC hotspots to make drivers aware of *M. meles*. As a result of the strong seasonal skew of *M. meles* WVC, seasonal warning signage should be installed for use at night from early spring to late summer. In areas where high WVC mortality is recorded, the warning signage should be kept year round.

(3) Traffic calming

Use speed-reducing measures such as speed bumps, either temporarily or permanently, to reduce vehicle speeds and volumes. *M. meles* are hard to see when they are active at night. Thus, a low speed limit, from 15–25 mph, is suggested.

(4) Removing grass verges on roadsides near WVC hotspots

Roadside vegetation is kept short and is a good place to search for earthworms, the mainstay of the *M. meles*'s diet. It is a trap that attracts *M. meles* to roads, especially when drought conditions prevail (Wildlife Online, 2014a). Remove grass verges along roadsides within 50 m of hotspots. Remove worm-rich soil and vegetation cover on roadsides to prevent them from becoming a trap for foraging *M. meles*.

(5) *M. meles* reflector

Reflectors scatter headlight beams off the road, thereby deterring *M. meles* from crossing at night.

Although reflectors are widely implemented mitigation measures for deer, there is little evidence that they help reduce badger WVC (RSPCA, 1994). Some evidence has shown that *M. meles* may soon become accustomed to the presence of reflectors (Wildlife Online, 2014a).

Badger reflectors should be 30 cm high with either a stainless steel or a dimpled mirror reflector, staggered along both sides of roads at 15 m intervals. Figure 6.1 gives an example of badger reflector design:

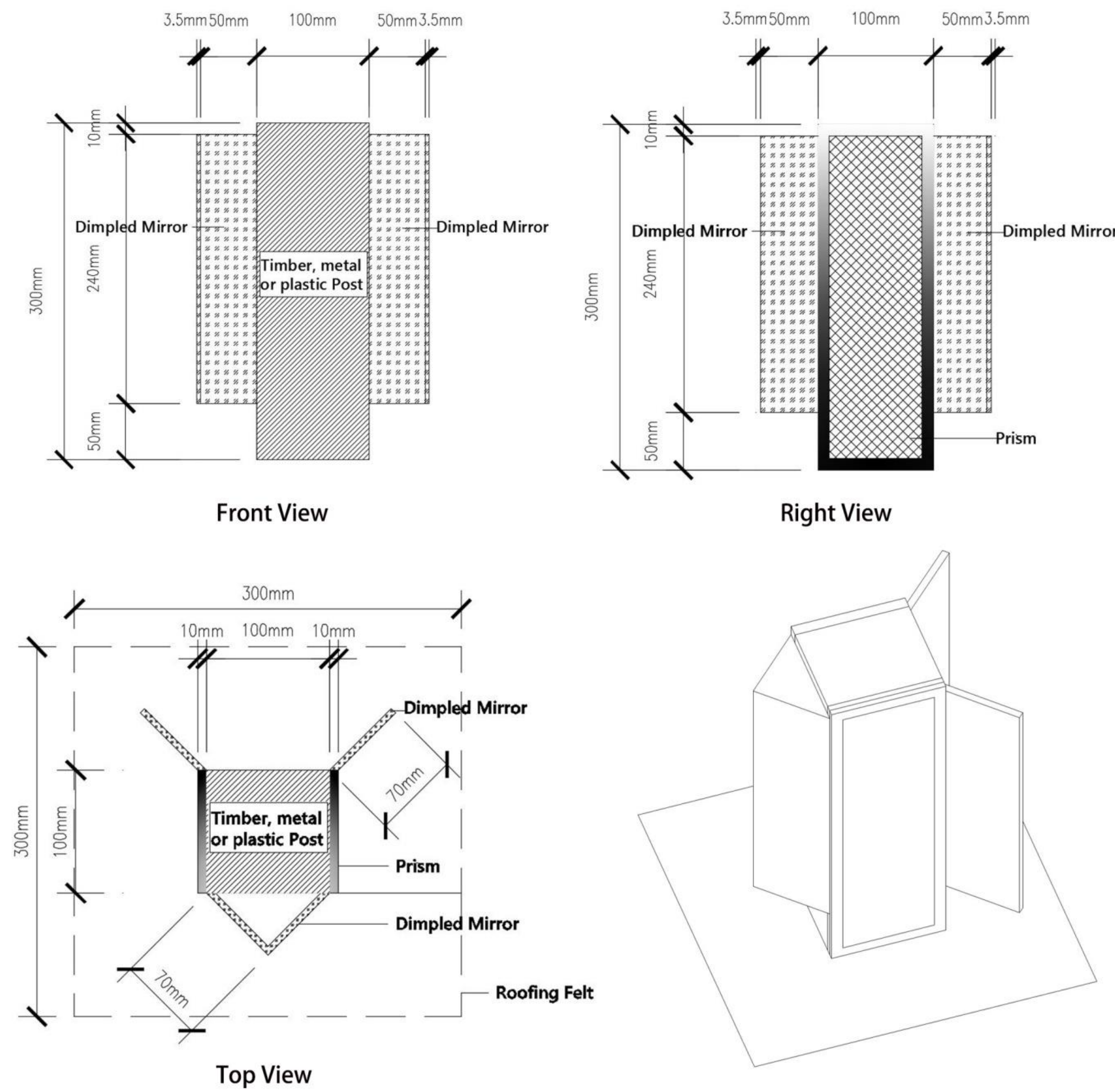

Figure 6.1: Badger Reflector Design
Source: Prepared by the author.

Reflectors need maintenance after installment. Suppress the growth of vegetation in spring and summer for 2 m around the post to ensure the reflection is not blocked. In addition, stainless reflectors need to be cleaned regularly to make it work effectively.

(6) Fences

There are many types of recommended fencing, but there is no firm information on the effectiveness of any of them. No fence is absolutely *M. meles*-proof. Theoretically any solid panel with a slippery surface could be used as an exclusion fence for *M. meles*, such as concrete or hard wood. Badger fence produced by TWIL Group[14] is made of 2.5 mm diameter bezinel-coated wire and come in rolls 25 meters long and 145 cm high. It can be fitted to specially made light-weight metal posts or to conventional wooden posts. This fencing is easily installed and relatively cheap (RSPCA, 1994).

Sometimes *M. meles* is very determined to cross, and it is good at digging, so it is important that any type of fence is at least 125 cm high, dug 50 cm into the ground with a right angle bend in toward the field (RSPCA, 1994). Fences should be higher and dug deeper at WVC hotspots where *M. meles* are likely to make a determined effort to cross.

Fence design principles include:

- Try to end a fence at a hedge line, and turn it back along the far side of the hedge for a short distance (RSPCA, 1994).
- Netting should be turned outward at soil level and covered.

[14] TWIL Group Export Limited was set up in the U.K. and has since dissolved. It produced specially designed badger fencing.

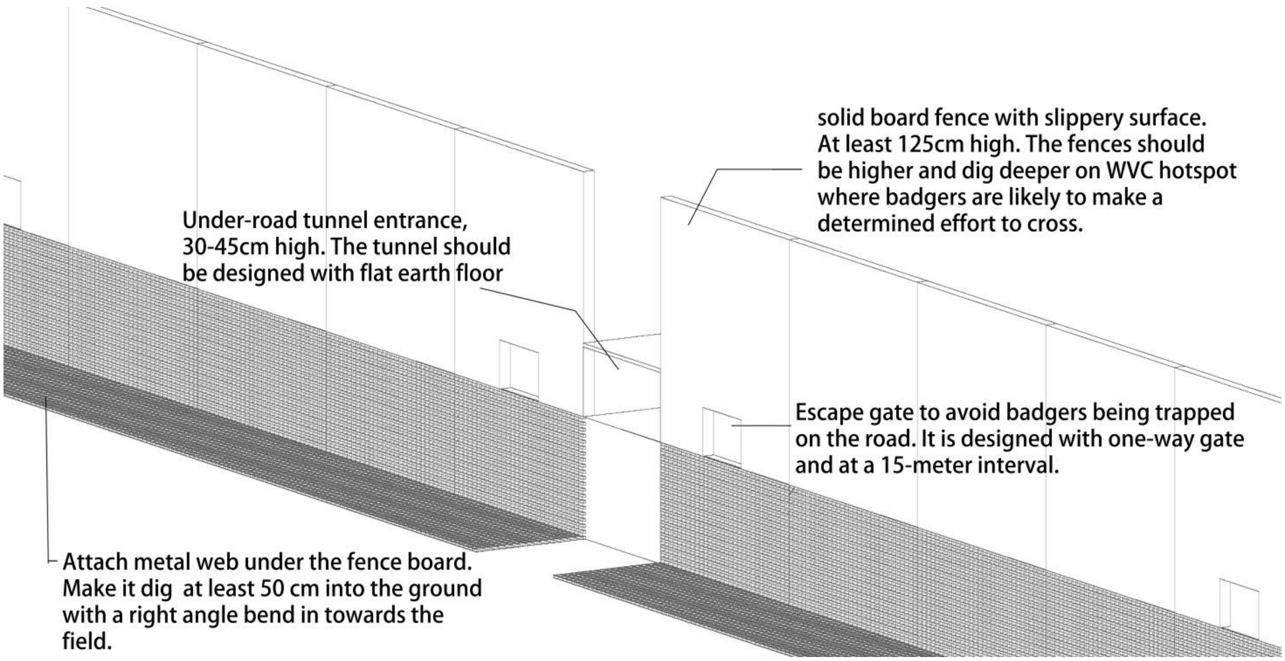

Figure 6.2: Exclusion fence Made of Solid Board
Source: Prepared by the author.

(7) Artificial badger paths

Designed corridors should incorporate existing badger paths, and connect badger setts to funnel movements. A connection is established using features such as hedges, trees, riparian strips, and shrub lines (Scottish Natural Heritage, 2015).

To enhance a corridor's leading function, use a hedge line or some other linear feature; low walls or fencing should be placed on either side of paths, to lead badgers to the crossing entrance. The corridors need to be left undisturbed by covering with plenty of plantings and ensuring no public access.

(8) Crossings

Crossings together with guiding fences are the most frequently implemented mitigation measures for mammals. These have proven to be efficient to decrease *M. meles* WVCs (Dekker and Bekker, 2010; Kinley and Newhouse, 2009; Vink *et al*., 2008). Since 1990 such measures have become an integrated part of roadway construction and renovation projects in the Netherlands (Finch, 2000; Vink, 2008). To maintain the effectiveness of crossings as mitigation measures, the following requirements need to be satisfied:

- The entrance of the crossing is visible. Grass and snow may obscure the tunnel entrance (Kinley and Newhouse, 2009). Keep a few square meters near the crossing entrance clear of vegetation to increase its visibility. A clear entrance will encourage *M. meles* to use it.
- Exclusion fence is needed in associated with the crossings to guide *M. meles* to the crossing tunnel and avoid crossing at any other point. The length of fence depends on the size of the badger group's range, but normally at least a set of 1000 m long fences are needed (RSPCA, 1994). To a large extent, successful use of these crossings depends on fencing quality.
- Adequate numbers of crossings are needed. Even though crossings are not designed for *M. meles* purposely, they will decrease WVC significantly. Kinley and Newhouse (2009) suggested that a spacing of

500 m between crossings may be appropriate, some other researchers recommend a shorter distance, 150–300 m (Clevenger and Waltho, 1999).

Crossings that could be used by *M. meles* include existing crossing infrastructures and specially designed *M. meles* tunnels.

(a) Existing crossing infrastructures

M. meles crossings may use existing infrastructures. Intentionally constructed underground tunnels are expensive (RSPCA, 1994). When crossing infrastructures exist near badger habitats, they can be used as *M. meles* crossings. As discussed before, badgers have been observed using these to cross. If there is an existing crossing near a WVC hotspot, it can be retrofitted to act as a mitigation structure. Infrastructures that can be used as crossings by *M. meles* include the following:

- Drain pipes. Concrete drain pipes with aperture diameters no less than 60 cm can be used as *M. meles* tunnels. Pipes with a "U" or "V" shape do not have flat bottoms. Retrofitting them to permit *M. meles* to move on a dry, safe surface is important (Kinley and Newhouse, 2009). To avoid slipping, a gravel soak away or drainage section is recommended. A guiding path to direct badgers to the pipe entrance is also needed.
- Culverts. *M. meles* can swim but it prefers other means to cross a stretch of water (Neal, 1986). It is important to add a ledge no less than 50 mm wide, at least 30 mm higher than the water level to ensure it stays dry during the wettest part of the year. The surface of the ledge should be a natural material to attract *M. meles* to use it and prevent them from losing

their balance when crossing. A tree trunk or lodge is ideal to be used as a ledge for *M. meles* to cross the culvert.

- A natural gully. A drainage system is required to ensure that there is no risk of flooding (RSPCA, 1994). A ledge is needed to help *M. meles* cross.
- Overpasses and underpasses built for livestock and farm machinery can be used as *M. meles* crossings.

(b) Designed *M. meles* tunnel

When there is no existing crossing near the WVC hotspot, *M. meles* crossings should be designed and constructed. Normally a *M. meles* crossing is designed as a tunnel, similar to the tunnels in a sett. The design principles of a constructed *M. meles* crossing include the following:

- Concrete sewer pipes have been used for tunnels in *M. meles* crossings and artificial badger setts. Concrete is immensely strong and not easy for *M. meles* dig through, so it is recommended for use in badger crossings. The bottom of a concrete pipe is slippery and difficult for *M. meles* walk through. Thus, purposely constructed badger tunnels are suggested to be designed in a horseshoe shape, with the bottom open. This allows *M. meles* to walk on flat earth. Soil is a natural material that is more acceptable for *M. meles*. In addition, soil is permeable, and this reduces the risk of flooding.
- Most crossings use a concrete pipe with a diameter of 600 mm (Neal, 1986; RSPCA, 1994), much bigger than natural tunnels in *M. meles* setts,

which are typically 300–350 mm (Pearce, 2011). Big tunnels allow wind and dust in, which will prevent use by the badgers. *M. meles*'s underground environment is damp and dust free, which is good for their nostrils (Pearce, 2011). Thus, an under-road tunnel should be designed to be 300–450 mm in height.

- Topographical characteristics should be considered to guide the selection of sites for new crossings. When terrain dictates that *M. meles* approach a road from below, they are more likely to find the entrance of an under-road crossing (Kinley and Newhouse, 2009).

(9) Scent-marking techniques to re-route *M. meles*

M. meles are scent-sensitive. Smearing some substance impregnated with badger scent around the crossing entrance and along the designed badger path may encourage use.

Such substances include the following:

- Dung from dung pits
- Spoils from heaps around the setts, discarded bedding (may include dry grass, straw, leaves, etc.), or badger hair

This is all the encouragement badgers require, but for extra insurance, people can lay a trail of peanuts from badger setts to the crossing entrance along the designed path. Place the peanuts late in the evening when most birds have finished feeding. Repeat it for several nights. See if the badgers are finding and taking the food; but leave them to it and do not watch for long because human scent will deter them from the new path (Pearce, 2011).

(10) Construct a network to funnel movement of *M. meles*

The animal's natural habitat is a network of paths, setts, and foraging areas. A new planned network should be designed to funnel movement to avoid WVC, based on the natural network that was investigated through field work. All WVC mitigation measures should be considered as part of the network. Figure 6.3 shows an example of a network.

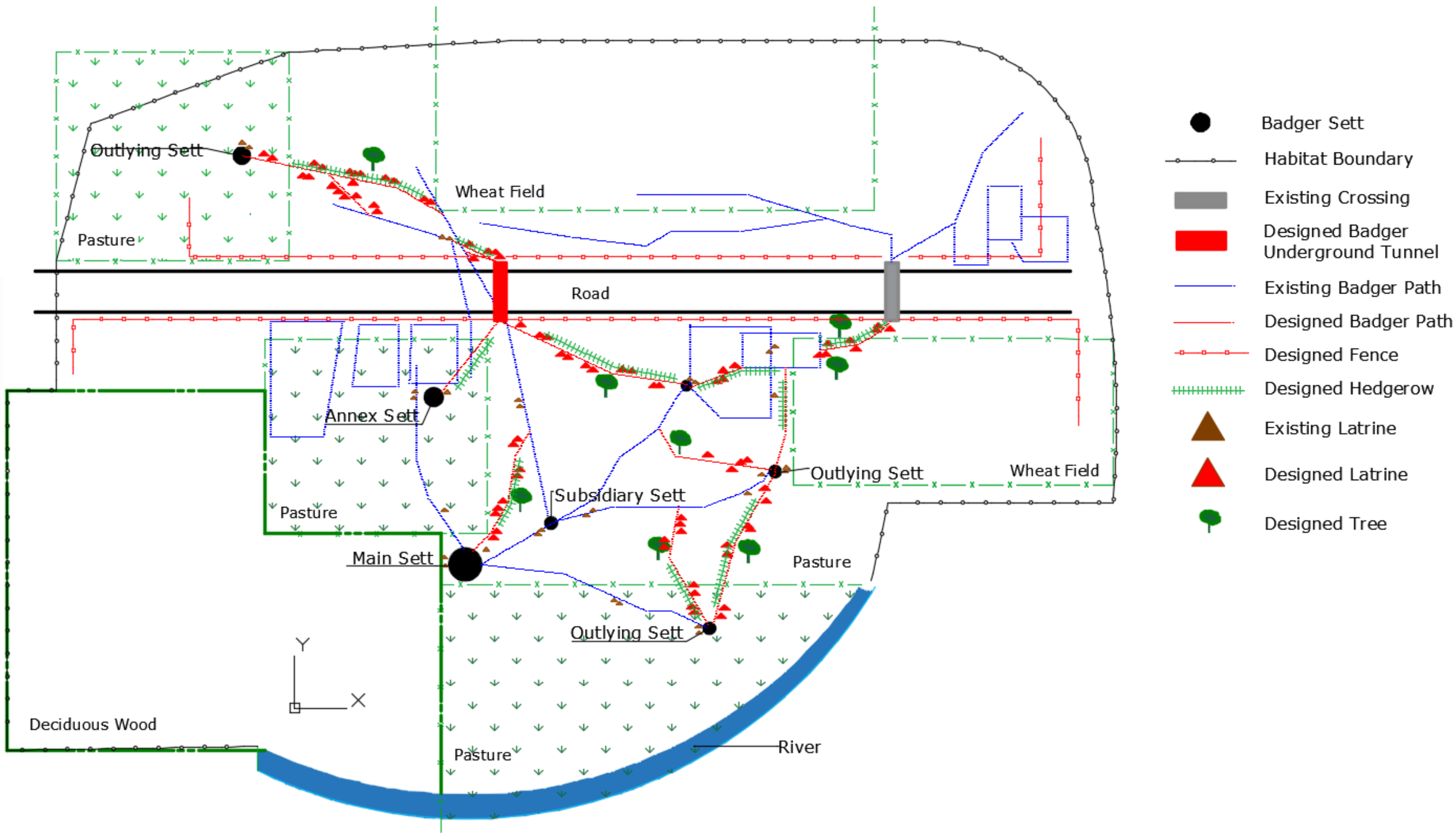

Figure 6.3: *M. meles* Network
Source: Prepared by the author.

(11) Translocate the badger group

When it is impossible to implement a mitigation measure for a specific WVC hotspot, and an alternative sett (sometimes maybe an artificial sett) exists within *M. meles'*s home range, it can be necessary to translocate an entire group of animals threatened by a road scheme (Neal, 1986; RSPCA, 1994).

The main means of translocation is to stink the *M. meles* out. It is best to wait until all the occupants have left, between 23:00 and midnight. Every sett entrance is stuffed with newspaper soaked in diesel fuel or some other repellent and then lightly plugged with earth. *M. meles* will detect the smell when they return later in the night. They will not attempt to re-open the holes, but instead will go to the alternative sett. Translocation should not be used between February and May when young cubs may present (Neal, 1986). Translocation is a last resort as a WVC mitigation measure.

Figure 6.4 shows an evaluation of the presented plan options based on deep ecology principles. The options with high effectiveness are more likely to eliminate WVC in long term. These options should be highly recommended for implementation, especially when local WVCs frequently occur.

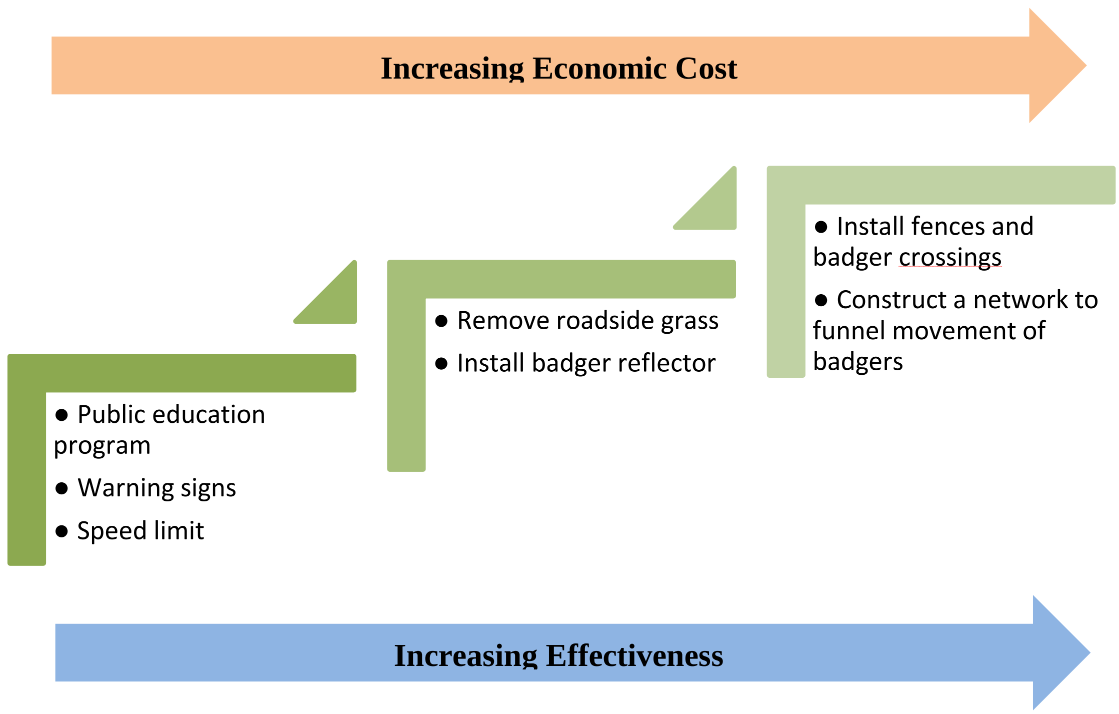

Figure 6.4: Evaluation of The Presented Plan Options
Source: Prepared by the author.

The final mitigation strategy depends on individual site circumstances (Barker, 2009). The mitigation committee should use the risk assessment and survey information to design an effective mitigation strategy for *M. meles*. Economic valuation could be used to rank the mitigation measure options, but every loss of an animal in WVC should be paid attention by planners.

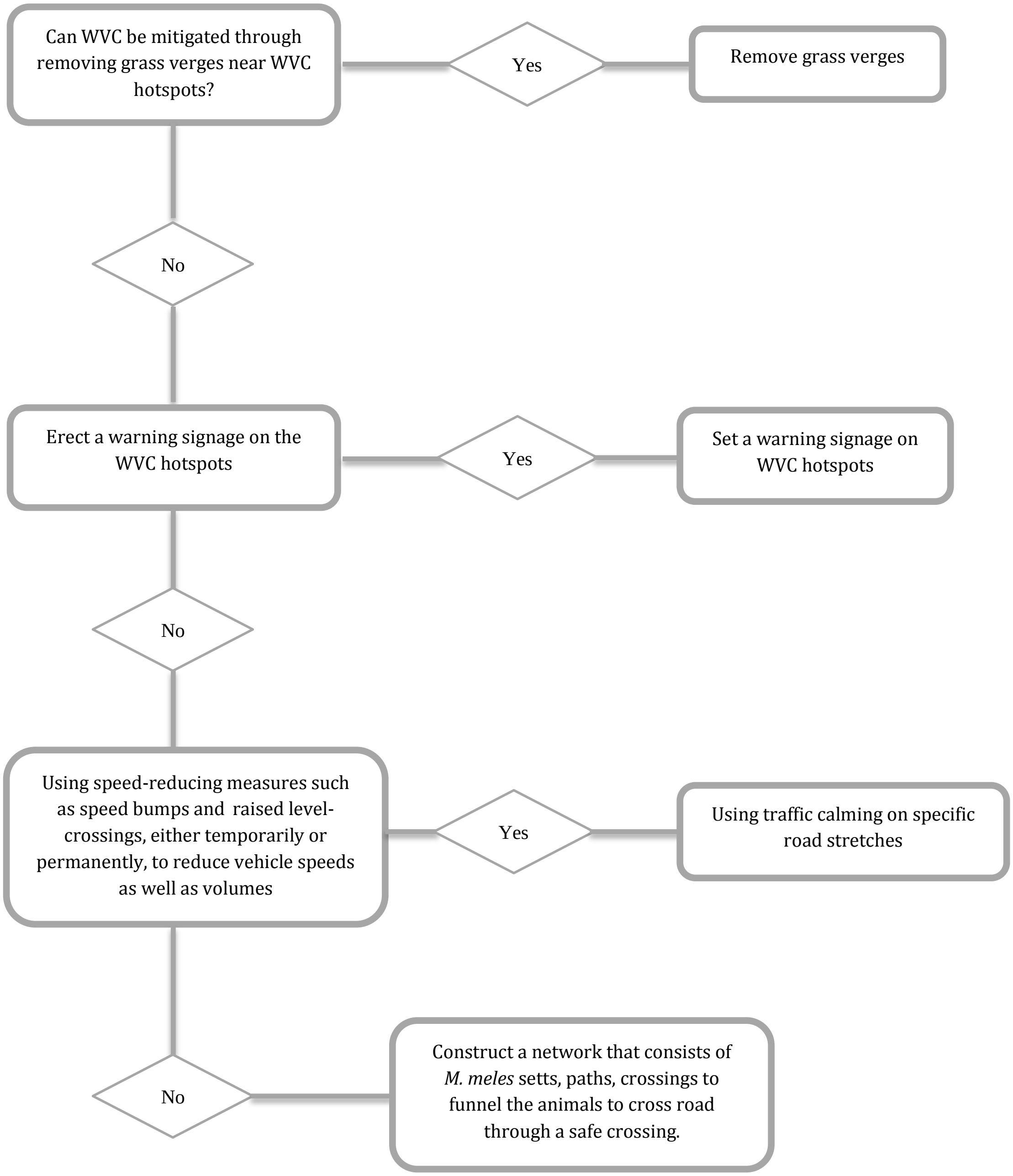

Figure 6.5: Decision-making Process on WVC Mitigation Measures for *M. meles*
Source: Prepared by the author.

6.2 Eastern Gray Squirrel (*Sciurus carolinensis*)

6.2.1 Basic biology

S. carolinensis is a medium-sized tree squirrel (Hinterland Who's Who, 2016; Lundgren, 2011). The total length of the adult ranges from 380 mm to 525 mm including a bushy tail, and the weight ranges from 300 g to 750 g. (BioKids, 2016a; Gareth Stevens Library, 2009; Koprowski, 1994; Smithsonian National Museum of National History, 2016). *S. carolinensis* is native to areas east of the Mississippi River in the United States. This adaptable species has been introduced to some parts of the western United States and some areas of Canada. It has also been introduced to Ireland, Britain, and South Africa. *S. carolinensis* is classified as Least Concern on the IUCN red list (IUCN, 2016b).

6.2.2 *S. carolinensis* and WVC

Squirrel family as a whole is frequently mentioned as a WVC victim in surveys and reports. For example, the date from the Isle of Wight shows that of the 158 gray squirrels (including eastern and western gray squirrels) found dead between September 2008 and October 2009, 123 (78%) had been hit by cars (Wildlife Online, 2014b); The Roadkill Observation System reports that squirrels turns out to have the third highest absolute number of WVC fatality of all the species. In some states of the U.S. such like Maine it stands as the top victim (Good2Go, 2013). As a member of squirrel family, *S. carolinensis* is on the victim list in WVC survey conducted in various locations. For example, in a research committed in a suburban garden in

England, WVC casualties account for 55%-75% of the total adult mortality (Shuttleworth, 2001); *S. carolinensis* stands more than 20% of mammal WVC victims in Oxley *et al*.'s survey in Canada (Oxley *et al*., 1974); Gray squirrels (including eastern gray squirrel and western gray squirrel) account for 17% of all WVC fatalities in Slater's study conducted in mid-Wales (Slater, 2002).

The reasons why *S. carolinensis* is a common WVC victim are easy to identify:

- *S. carolinensis* is abundant in cities. The species has been urbanized for more than a century (Benson, 2013). The urban landscape with its systematic and continuous green network is an ideal predator-free habitat for *S. carolinensis*. Small lots with single-family homes surrounded by gardens and trees and urban parks provide a set of protected enclaves large enough to harbor substantial squirrel populations. In urban areas, *S. carolinensis* populations are abundant in parks, college campuses, and cemeteries (Williamson, 1982/1983).
- The typical defensive behavior of *S. carolinensis,* which has been well adapted to their natural predators, increases their likelihood of being hit by cars. When chased by predators, it dodges to and fro in an attempt to out-maneuver the predator. When it reacts similarly to the threat of an oncoming vehicle, this strategy that is successful in the natural world quickly becomes fatal, as the animals dodge directly under a wheel (Grant, 2004; Thorington and Ferrel, 2006).

- Even though it is a tree squirrel, *S. carolinensis* spends a lot of time foraging on the ground, especially in spring and summer when food in the canopy is relatively scarce. Human-provided food and intense hoarding activities in autumn increase its time spent on the ground.
- Greater movements occur in fragmented woodlands than in areas of more continuous woodlands. Fragmented landscapes always correlate with roads in urban areas.
- Trees and plants on roadsides and in the median strip, especially nut- and acorn-bearing species, are attractive shelter and food sources for *S. carolinensis*.

Characteristics of *S. carolinensis* WVCs are outlined as follows:

- WVC casualties show a strong seasonal pattern, with a peak in the autumn months. High WVC occurrence in autumn is associated with the species' intense foraging and hoarding activities and the population peak as a result of young weaning (Brandl *et al.*, 1991; Shuttleworth, 2001). In this season, the adult *S. carolinensis* often makes long-distance journeys to exploit known sources of natural or supplemental food. Their hoarding behavior could lead squirrels to cross roads more frequently while searching for a location to cache food. WVCs in winter are not significant. This phenomenon is attributable to a reduction in the amount of time animals are active out of the nest (Shuttleworth, 2001).

- The daily peak time for WVC is about 2 h after sunrise and 2 h before sunset, which often coincides with rush hours when maximum traffic occurs. High traffic volume leads to more WVCs (Shuttleworth, 2001).
- Juveniles are particularly vulnerable to WVC. Experience is important, as many road-killed *S. carolinensis* would seem to be traffic-inexperienced young individuals (Slater, 2002). Juvenile dispersal contributes significantly to WVC mortality (Koprowski, 1994). The juvenile dispersal rate is affected by population density. In urban habitats, *S. carolinensis* juvenile dispersal may occur more often, and the dispersal distance is farther.

Common mitigation measures for squirrel WVC are warning signs and areal rope bridges. Rope bridges for squirrels have been used in some locations with varying success (Red Squirrels Northern England [RSNE], 2016). The first squirrel bridge was documented in 1963 in Longview, Washington, U.S.A. The mini suspension bridge spans 18 m and is made of aluminum piping covered with a retired firehose. Others have followed in the UK, Belgium, France, and the Netherlands (Berlin, 2014).

However, WVC mitigation measures for squirrels are not as widely developed or implemented as for larger animals. One important reason is that compared with its high reproductive rates, WVC mortality is sustainable in this abundant species (Glista *et al.*, 2007). *S. carolinensis* is considered an invasive species in some districts, so conservation efforts always exclude this species. In addition, *S. carolinensis* is not a menace to road safety due to its tiny body size. Research is needed to further develop effective approaches to mitigation. Generally, mitigation measures to reduce *S. carolinensis* WVC should be similar to mitigation measures for endangered arboreal species. Nevertheless, it is essential to consider *S. carolinensis*'s specific movement patterns due to its large amount of foraging time on the ground.

6.2.3 *S. carolinensis* ecology and WVC mitigation suggestions

Table 6.3: *S. carolinensis* Ecology and WVC Mitigation Suggestions

	Behavior	**WVC Mitigation Observations and Suggestions**
Reaction to Roads	There are conflicting statements about squirrel reactions to roads. Some research found that they had no sense of roads during on-the-ground travel and that 25% of squirrels are killed during road crossings (Ryan and Carey, 1995); while others stated that squirrels become more skilled in road crossing with age. Squirrels avoid vehicle predation by crossing roads on wires or other means (Thorington and Ferrell, 2006).	Thorington and Ferrell's (2006) work implied the feasibility of aerial passages as WVC mitigation structures.

	A study in the U.K. found that gray squirrels used the canopy of trees along the edges of roads to move between adjacent woods (Michael, 2005).	*S. carolinensis* does not avoid roads, which implies the possibility of constructing an aerial bridge for them to cross over.
	During dispersal movements, squirrels do not avoid roads. (Fey *et al*., 2015).	Dispersing *S. carolinensis* are highly susceptible to WVC.
	A combination of road width, traffic volume, and vehicle speed affects squirrel WVC occurrence (van der Ree, 2006).	Traffic calming could be a useful mitigation approach.
	S. carolinensis shows a stronger tendency to cross roads with clearances[15] between 14 and 35 m, and cross wider roads less frequently (Oxley *et al.*, 1974).	Higher WVC mortality may occur on narrow roads (14–35 m) running through woodlands in parks, campuses, and residential areas than on wider roads. It makes sense to focus mitigation measures on narrower roads in such locations

[15] The term "road clearance" as used here refers to the distance an animal has to move between vegetated margins to cross a roadway. Clearance may be equivalent to right-of-way, but this is not always the case (Oxley *et al.*, 1974).

Breeding and Nesting	*S. carolinensis* can breed twice a year if food is abundant. The first litter is born in spring and the second in summer. Only 25% of squirrel kits survive to one year of age (Koprowski, 1994). Juvenile dispersal happens 90–120 days after birth.	More juveniles will be on roads 3–4 months after the local breeding season. More mitigation efforts should be undertaken at this period.
	Mating chases result in increased activity of local populations (Oxley *et al.*, 1974).	Mating chases may cause WVC.
	In spring and summer, usually *S. carolinensis* builds nests made of leaves on branches. This kind of nest is also called "drey"; in winter, it builds new nests in holes in trunks and thick branches of trees. The drey is big enough to be noticeable. In winter several squirrels may share the same nest.	Human observers can identify the presence of *S. carolinensis* through this noticeable sign. In winter a drey or den implies more than one animal.
	Leaf nests are most often found high up in large pine, hemlock, maple, birch, or oak trees. The nest consists of a platform of twigs on a tree limb, a compacted base of decaying matter, an outer shell of twigs and leaves, and a lining of shredded material. (Hinterland Who's Who, 2016; Koprowski,	Rest stations designed similarly to natural nests could be set along aerial bridges.

	1994).	
	S. carolinensis populations are abundant in forests with tree cavities (Williamson, 1982/1983).	Mature trees with cavities are attractive for nesting.
Foraging Pattern	*S. carolinensis* is diurnal. They are generally active throughout the day, while activity diminishes to about four hours or less (in the mornings) in winter, before increasing again to between three and eight hours (Wildlife Online, 2014).	Raise public awareness of daily peak times for foraging activities.
	Main food sources for in different seasons include the following: Spring—buds of several types of hardwood trees, particularly maple. Squirrels lick the sweet sap that leaks from cracks in the bark of maple trees (Lundgren, 2011). Summer—winged seeds of maple and elm, together with a wide variety of berries, fungi, and other wild fruits. Autumn—acorn and hickory nuts. Winter—Food stored during autumn and sometimes food supplements from human. *S. carolinensis* often takes advantage	Maple seed in summer, tree buds in spring, acorn and hickory nuts in autumn, and bird feeders in winter are attractive to *S. carolinensis*. Road stretches with hardwood trees around them are sensitive areas for WVC.

	of bird feeders as a food source (Lundgren, 2011).	
	Squirrels are more common where supplemental food is available than where it is not, particularly during harsh or snowy winters. *S. carolinensis* populations are abundant in sites with bird feeders (Benson, 2013; Bowers and Breland, 1996). Human food waste also provides a year-round source of nourishment that partly makes up for the paucity of natural food. Supplement food increases foraging time on the ground. Availability of supplemental food is a factor in high WVC mortality in urban areas (Shuttleworth, 2001).	Avoid human-provided food and other supplement food sources like bird feeders that attract squirrels to cross roads.
	In spring, habitat quality experiences a seasonal change, which may make *S. carolinensis* roam further to seek food (Thompson, 1977).	In spring the animals may travel further from their home trees.
	WVCs occur when squirrels forage on the woodland floor. Activity on the ground is increased when food in the canopy is relatively scarce. *S. carolinensis* also spends a lot of	A squirrel bridge that connects the canopy across a road may not be adequate to mitigate WVC. In autumn and early winter

	time on the ground when scatter hoarding of food is intense (Shuttleworth, 2001).	when hoarding activities are intense, WVCs occur more often.
	S. carolinensis eats a lot and stores fat during the warmer months. In autumn its rate of food consumption exceeds energetic needs by 32% (Koprowski, 1994). In winter it climbs out of its nest every few days to search for fresh food or for food it hid away earlier (Gareth Stevens Library, 2009).	*S. carolinensis* stays active all winter, although it is not as active as in summer due to the stored fat in its body. This sluggishness increases the likelihood of WVC in winter. Mitigation measures are still needed in winter.
	S. carolinensis consumes twice as much as food at $<4^{o}C$ as individuals at $24^{o}C$. Maximum body mass occurs in autumn and winter (Koprowski, 1994).	Its sluggish movement in autumn and winter make them more likely to be hit.
	Squirrels' diet-activity patterns are bimodal from spring to autumn, peaking about 2 h after sunrise and 2–5 h before sunset; a unimodal pattern occurs in winter with a peak 2–4 h before sunset (Hinterland Who's Who, 2016; Koprowski, 1994). *S. carolinensis* is most active in summer (Diemer, 2006).	Increased activity is associated with increased WVC. Spread information about peak foraging times through public education systems to improve awareness.

	Greater movements would occur in fragmented woodland than in areas of more continuous woodland (Taylor *et al*., 1971).	Urban areas have more fragmented landscapes. *S. carolinensis* in urban areas have greater movements, which implies higher WVC occurrence.
	From late autumn to winter, squirrels spent most of their time traveling on the ground, digging and foraging for buried acorns. Travel decreases in late spring and summer, then increases in late fall (Ryan and Carey, 1995).	Autumn is the peak time for *S. carolinensis* WVC. Increased foraging time on the ground may be one reason.
	S. carolinensis is especially attracted to sugary beverages and milk (Hinterland Who's Who, 2016).	Outdoor drinking fountains and trash cans containing food waste may attract squirrels. Design barriers around these attractors.
Movement Pattern	Squirrels spend most of their lives in trees, where they move about with great agility. A continuous tree canopy allows easy travel from tree to tree.	Aerial crossing structures should be designed between trees to help squirrels move above traffic. Extension of crossings to adjacent forests can encourage use.
	S. carolinensis has great mobility and can reach speeds up to 25 km per hour. Squirrels can jump about four feet high, or nine feet	There are no experimental data on how far *S. carolinensis* can jump or glide. A continuous crossing

	horizontally with no incline change. They can glide briefly (Hinterland Who's Who, 2016; Squirrels in the Attic, 2016).	structure is appropriate for its safe movement.
	S. carolinensis runs along branches and leaps between trees on familiar paths. Pathways have squirrel scent marks to help them easily find their way (Gareth Stevens Library, 2009).	Scent mark designed squirrel passages to improve their effectiveness.
	S. carolinensis's hind feet are strong and flexible, allowing them to climb and hold on to slippery surfaces. They are frequently observed walking along wires "at lightning speed" (Benson, 2013, p. 700).	Telephone and electric power lines can be used as crossing structures for *S. carolinensis*, even though these facilities are not specifically designed as squirrel passages.
	There are many records of *S. carolinensis* swimming (Thorington and Ferrell, 2006).	Culverts with water can be used as tunnels for squirrels to cross under roads.
Habitat Characteristics	Densities of the squirrels are highest in habitats composed of trees that produce storable foods such as oak, hickory, and walnut (Koprowski, 1994).	A land patch with a diversity of nut-bearing trees can support a large population.
	Although undisturbed forests are the squirrel's favorite habitat, its population density is much higher near human settlements, and is	Urban parks, reserves, or campuses may host large *S. carolinensis* populations. Roads running through or

	especially high in heavily forested urban and suburban sites (Bowers and Breland, 1996).	along these landscape patches need special attention in WVC mitigation strategy development.
	S. carolinensis abundance in urban areas is significantly correlated with basal area, tree density, and number of oaks per ha. When the diameter at breast height (d.b.h.) of all species of oak trees reaches 43 cm, they produce acorns at the average for the species (Williamson, 1982/1983).	WVC hotspot identification in urban area is associated with basal area, tree density, presence of mature oaks.
	S. carolinensis prefers to nest in trees greater than 31 cm in diameter. Oaks and pines are usually chosen as nest trees (Williamson, 1982/1983).	Mature trees with diameters greater than 31 cm in woodland patches are attractive to *S. carolinensis*.
	A minimum of 8.5 m^2/ha of basal area in trees of seed-producing size[16] is the ideal habitat size to sustain reasonable *S. carolinensis* densities (Williamson, 1982/1983).	Roads running through or along these areas are putative WVC hotspots.
	Typical signs of *S. carolinensis* inhabitation are gnawed husks and shells of nuts around the base of a tree, especially acorns, hickory nuts, walnuts, beechnuts, and	These signs should be used in a field survey to identify local habitats of *S. carolinensis*.

[16] Seed-producing size is >25.4 cm. d.b.h. (Williamson, 1982/1983).

	pecans (Hinterland Who's Who, 2016).	
	Following a period of expansion, the area used by *S. carolinensis* individuals appears to stabilize and remains identical in both extent and location throughout life. Each squirrel occupies an average home range of 1–3 acres (0.4–1.2 ha) in areas with high population density and 50 acres (20 ha) in areas with low population density. Its range is greatest during spring (Thompson, 1977). *S. carolinensis* possesses a strong homing tendency and may return from ≤ 4.5 km (Koprowski, 1994), but its maximum travel distance is 180 m (Taylor *et al.*, 1971).	It is possible to draw a range for *S. carolinensis* activity. Drawing the activity range of *S. carolinensis* can help identify potential WVC hotspots. In urban areas where *S. carolinensis* density is high, the range is about 1 acre. The activity range of *S. carolinensis* can be drawn as a circle with the home tree as the center and the maximum travel distance as the radius.
	Male squirrel home ranges expand significantly during the summer mating period (Thompson, 1977).	Enlarge the home range of *S. carolinensis* to 3 acres in summer when designing a mitigation strategy.
	Plantings in parking lots and on street edges can provide adequate habitat for squirrels, which might be attracted from nearby forests	Roadside trees near forests may attract *S. carolinensis* for nesting. These nest locations increase the

	(Williamson, 1982/1983).	possibility of WVCs.
	Nest boxes offered by squirrel lovers are crucial to the establishment of squirrel populations in a specific landscape patch (Benson, 2013).	Nest boxes should not be installed in locations that may induce high WVC rates.
Social Behavior	*S. carolinensis* has a home range, but territoriality is not evidenced and many home ranges may overlap (Hinterland Who's Who, 2016; Koprowski, 1994). *S. carolinensis* freely cross overlapping home range boundaries when foraging and feeding (Thompson, 1977).	Many individuals may share the same corridors, crossing structures, and rest stations.
	The largest increments are added to subadult squirrels' home ranges between the ages of 90 and 120 days, which correspond to dispersal activities (Thompson, 1977). Juvenile dispersal contributes to high mortality during the first year of life (Koprowski, 1994).	Subadults actively expand their home ranges. The period of maximum home range expansion begins in summer for spring-born animals, and autumn for summer-born animals (Thompson, 1977).

	Population density affects dispersal rates (Oxley *et al.*, 1974).	In urban areas with large *S. carolinensis* populations, dispersal happens more frequently.
Others	Urban *S. carolinensis* individuals are so tame that they will come and take nuts out of human hands (Benson, 2013).	Supplemental food from humans attracts *S. carolinensis* activities. Use public education programs to educate people not to lure animals into crossing roads.

6.2.4 Suggestions for *S. carolinensis* WVC mitigation strategy development

6.2.4.1 Data collection

Data that needs to be collected for developing appropriate mitigation strategies fall into two categories: numbers of WVC-killed *S. carolinensis* and geographical ranges of routine activity. Through data collection, WVC hotspots can be identified in a GIS system. The two approaches for data collection are as follows:

- Public reporting system. The majority of carcasses are discovered as a result of reports made by local people (Shuttleworth, 2001). Public report system acts as an essential information source in *S. carolinensis* WVC research. Squirrel bodies remain visible on roads after WVC for an average of 2.7 days. This is realized as long enough for many carcasses to be reported by members of public. *S. carolinensis* is easily to be realized by the non-professional public due to its abundance in an area.

Nevertheless, there is still high possibility to under-estimated the number of WVC-killed *S. carolinensis*. That is because 1) carcasses may have gone unreported; 2) the passage of vehicles may render them shapeless and unrecognizable; 3) the carcasses may get eaten by scavengers before being reported; and 4) the *S. carolinensis* who is struck by vehicles but is able to move unseen is not included (Shuttleworth, 2001).

- Field survey. The first object of a field survey is to collect information on WVC-killed *S. carolinensis*. Field surveys can be conducted with the help from professionals, local experts, or the public. Patrolling potential WVC hotspots on foot or by bicycle once every 24 hours in autumn to look for *S. carolinensis* carcasses is recommended. Data can be collected weekly. The patrolling should be committed in autumn when has been proven to be the WVC peak season. Mortality may increase in areas where roads fragment or isolate areas of home ranges. Special attention should be given to the road segments that run through patches with sufficient food, shelter, and protection from predation.

Possible WVC hotspots may be found at the followed following locations:

- Road stretches where food resources can be found in adjacent land patches.
- Road stretches with nut- or acorn-bearing trees being planted on both sides of a road segments.
- Narrow roads with road clearances of 14–35 m (Oxley *et al.*, 1974)

- Road sections with wide, grassy median strips that encourage crossing attempts (Clevenger *et al*., 2003; Snyder, 2014).
- Areas where abundant *S. carolinensis* populations have been observed. *S. carolinensis* is easily observed in urban areas, so the sight records (tracks, live observation, and WVC-kills) of *S. carolinensis* may give reliable information on range (Taylor *et al*., 1971).

The second purpose of the survey is to locate the important ecological elements for *S. carolinensis*. These elements are not included in regular geographic information systems or satellite photos, but are helpful to identify home ranges, foraging sites, and activity ranges:

- *S. carolinensis* nests. Normally it nests in leaf dreys on branches in spring and summer, in tree cavities in winter. Dreys are big enough to be noticeable and they often are found on the top of large pine, hemlock, maple, birch, and oak trees. Rather than the continuous, undisturbed woodlands, the species' population density is high in landscape patches near human settlements.
- Vegetation composed of abundant and diverse plant and mature tree species, especially mast-producing trees like oaks.
- Mid-aged, mature, or old trees with their d.b.h. reaching 31cm. Special attention should be given when the d.b.h. of the mast-bearing trees reach 43cm.
- Abundant nest boxes supplied by squirrel lovers.

On the basis of collected information, a rough estimate of *S. carolinensis* home ranges can be drawn. The home range of an animal is defined as “the area it covers in its day-to-day travels. An inherent property of home range is that it is fixed, in the sense that the animal does not wander through a space at random but repeatedly covers the same general area” (Calhoun and Casby, 1958, p. 1). Mathematical expressions of home ranges are circular (Calhoun and Casby, 1958), although some researchers have recorded that ranges tend to be elongated (Mohr and Stumpf, 1966). For the purposes of this research only a rough conclusion is needed, so a circular shape is used. Taking the home tree as the center and the maximum travel distance—180 m—as a radius, draw a circle to define the home range. In spring, the home range may extend due to a seasonal change of habitat quality.

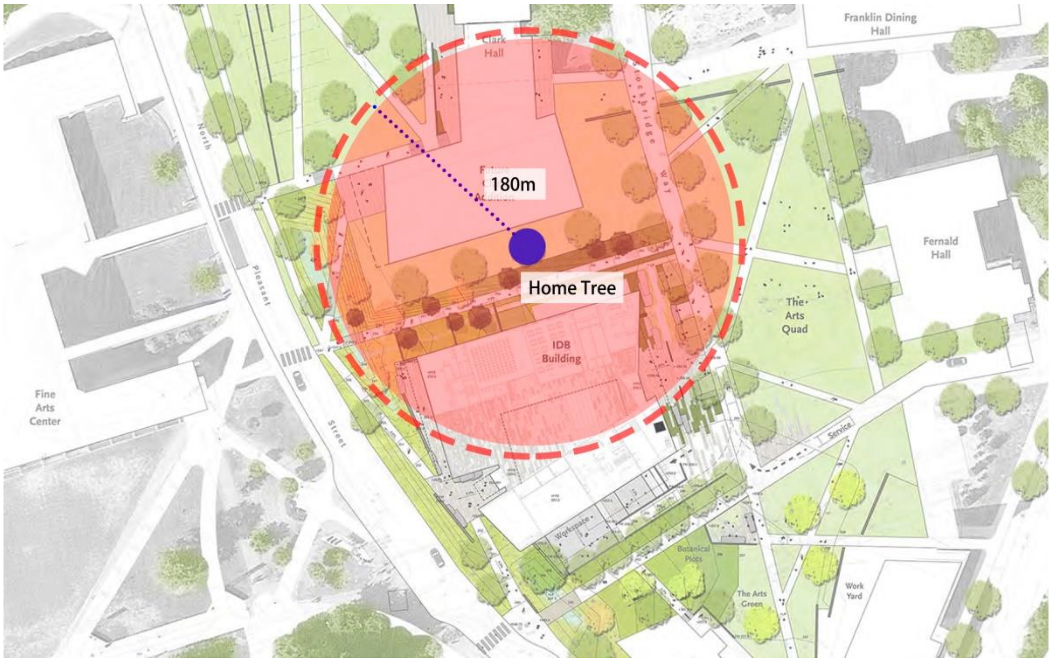

Figure 6.6: Typical Home Range of *S. carolinensis*
Adapted from photo source: http://bct.eco.umass.edu/wp-content/uploads/2014/07/IDB-Images_r-7.jpg.

6.2.4.2 Plan action options

(1) Public education programs

Ryan and Carey (1995) reported that raising public awareness of the presence and status of local *S. carolinensis* populations, as well as basic information on WVC avoidance strategies, through brochures and posted road signs may reduce *S. carolinensis* WVC rates. Elements to cover in a public education program include the following:

- Local sensitive areas for *S. carolinensis* WVC—encourage drivers to slow down in wooded areas (RSNE, 2016).

- WVC occurrence has a seasonal peak in autumn.
- The daily peak times for *S. carolinensis* activity are 2 h after sunrise and 2 h before sunset.
- Supplemental feeding opportunities offered by squirrel lovers should not be located in positions that encourage road crossing (RSNE, 2016; see Figure 6.7).

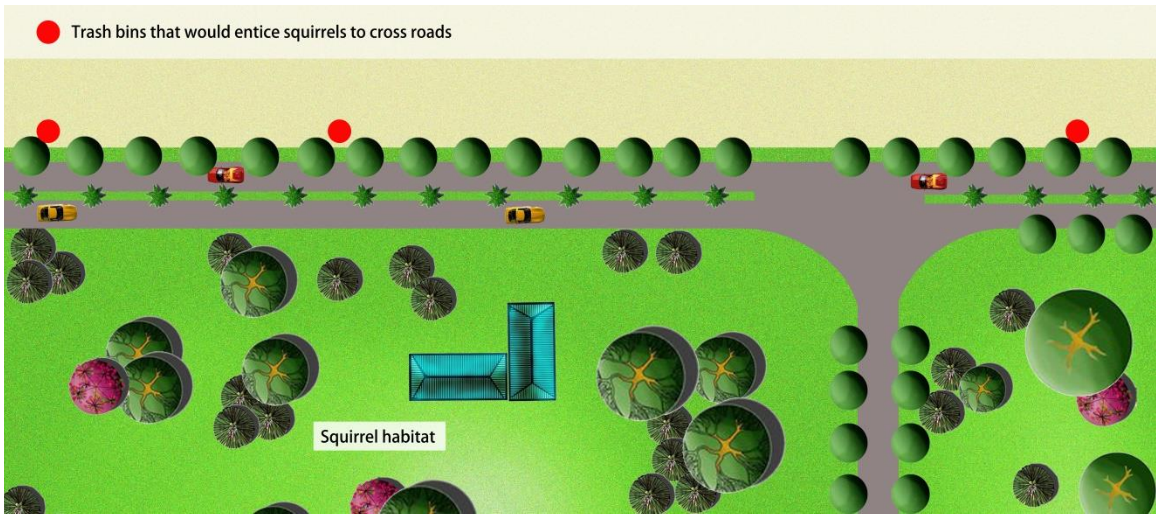

Figure 6.7: An Example of Roadside Attractants for *S. carolinensis*
Source: Prepared by the author.

(2) Clear roadsides of food and water resources

Remove frequently visited roadside food waste stations and water sources around WVC hotspots. Focus should be put on the trash cans near restaurants and transportation stations. Drinking fountains or puddles next to curbs may also attract *S. carolinensis*.

(3) Traffic calming

- Warning signage. Warning signs are widely used for mitigate WVC for *S. carolinensis*'s relative—red squirrel (*Sciurus vulgaris*) in some locations, but rarely for *S. carolinensis*. The warning sign for *S. carolinensis* should be similar to those for red squirrels. Signs should be erected in selected WVC hotspots. Avoid an over proliferation of the warning signs, Over proliferation of signs can significantly dilute their effectiveness. The signs could be designed as a 3.3m galvanized post with a triangular post on the top. The triangular post is 600mm, constructed from aluminum, and display a squirrel motif (RSNE, 2016). The post is also can be attached on a roadside tree.

Figure 6.8: Example Warning Signage for *S. carolinensis*
Adapted from photo sources: http://hildakean.com/?page_id=182 &
http://i.istockimg.com/file_thumbview_approve/42966650/3/stock-photo-42966650-red-squirrel-warning-sign.jpg.

- Speed limits. Traffic volume and vehicle speed are proven to affect S. carolinensis WVC occurrences (van der Ree, 2006).
- Road closures during WVC peak seasons. Close roads in WVC sensitive areas, mainly in forests and parks, to all vehicular traffic in peak seasons (Fitzpatrick et al., 1993). Roads can be re-opened at the beginning of winter.

(4) Clear road verges at identified WVC hotspots

S. carolinensis deaths in WVCs are most frequent on tree-fringed roads. Elevated roads or roads with a verge width in excess of 10 m had fewer WVCs than roads with close vegetation (Slater, 2002; Snyder, 2014). Clearing road verges of vegetation to more than 10 m is an effective approach for roads segments that run through continuous woodlands. An aerial bridge is recommended to mitigate the barrier effect of roads.

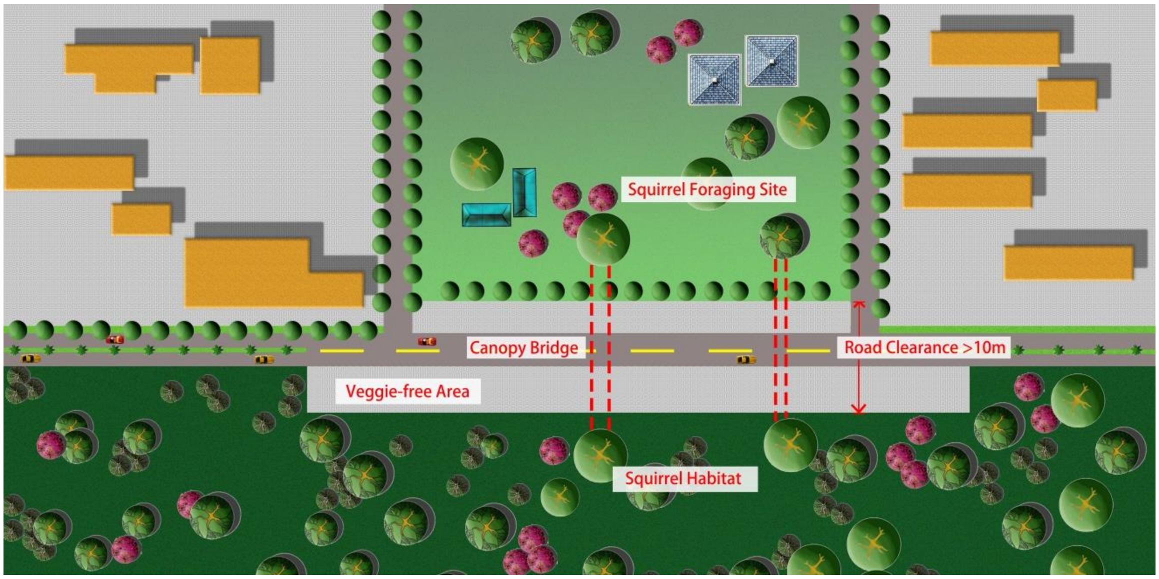

Figure 6.9: Road Verge Clearance
Source: Prepared by the author

(5) Design median strips to be less attractive to *S. carolinensis*

A wide variety of berries, fungi, and other wild plants are important food sources for this species, especially in summer. Avoid planting species that bear fruit in median strips.

Road sections with wide, grassy medians are possible WVC hotspots. A wide, vegetated median is seen as a safe zone by *S. carolinensis* as it decreases the distance the animal has to cross at one time to reach safety. Consider replacing the median with a hard surface if necessary. When it is not possible to remove plants from the median, place a warning sign or construct alternative crossings.

(6) Implement *S. carolinensis* crossings to facilitate crossing behaviors

S. carolinensis has been observed using existing aerial and underground passages to cross roads. Thus there are two options to construct an *S. carolinensis* crossing—aerial bridges and underground tunnels.

(a) Aerial bridges

S. carolinensis spends most of its life in trees, where it moves around with great agility. A continuous tree canopy allows easy travel from tree to tree. However, the animal's movement can be hampered by even a narrow gap at the same height. Although not widely implemented for *S. carolinensis*, aerial bridges are a common WVC mitigation measure for some arboreal species, like the squirrel glider (*Petaurus norfolcensis*), to combat habitat fragmentation. van der Ree (cited in Gray, 2006) stated that an aerial bridge is effective to "remove animals off the road and reduce the risk of collisions" (p. 2). Rope bridges are relatively inexpensive. If they are used extensively, aerial bridges can reduce WVC rates significantly. Some studies have observed that aerial bridges are used by arboreal mammals to cross roads. Regular usage by certain individuals are identified (e.g., Ball and Goldingay, 2008; Gray, 2006; Soanes and van der Ree, 2009; Taylor and Goldingay, 2013). However, the effectiveness of many of them are yet to be fully determined (Ball and Goldingay, 2008; van der Ree, 2006). Aerial bridges may be an effective WVC mitigation measure for the following reasons:

- Most arboreal medium-sized mammals have been recorded crossing aerial bridges. This indicates that this kind of crossing may work well for *S. carolinensis* (Teixeira *et al.*, 2013).
- *S. carolinensis* is an adept climber, so it would have no physical difficulty in using these aerial crossings.
- *S. carolinensis* does not avoid trees on road verges. A study in the U.K. found that gray squirrels used the canopies of trees along road verges to move between adjacent patches of woods (Michael, 2005).
- *S. carolinensis* runs along branches and leaps between trees on familiar paths, which means that after an initial period of habituation to artificial crossings, an increase in crossing frequency is likely to occur (Soanes and van der Ree, 2009).
- *S. carolinensis* avoids vehicles predation by crossing roads on existing wires or by other means. This indicates that it may use a bridge which is designed for it.
- During dispersal, juveniles commonly use habitat elements not preferred by adults, suggesting they may be willing to use artificial structures to cross roads (Ball and Goldingay, 2008).

Existing infrastructure like a couple of telephone poles can be strung with rope and used as aerial bridges for *S. carolinensis*. When no such infrastructure exists near WVC hotspots, or where existing infrastructure is not sufficient to facilitate movement, installation of an aerial bridge is recommended. Figure 6.10 shows design models for canopy bridges.

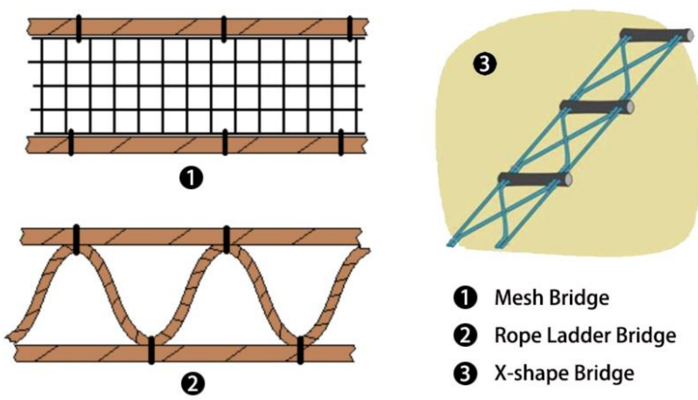

Figure 6.10: Models of Squirrel Aerial Bridge. Taken from: RSNE, 2016, p. 2.

Design principles of an aerial bridge include the following:

- Meet minimum height requirements set by local planning departments (RSNE, 2016); normally 6—12 m, depending on local topography (Soanes and van der Ree, 2008).
- Feeders or feeding platforms should be installed at either end of the bridge and replenished regularly to attract use, especially in the first months after installment (RSNE, 2016).

- When the aerial bridge is installed above a road that is wider than 5 m, design resting stations made of natural material every 5 m along the bridge to prevent *S. carolinensis* from falling off. The stations could be constructed with natural material to make them more acceptable by the squirrels.

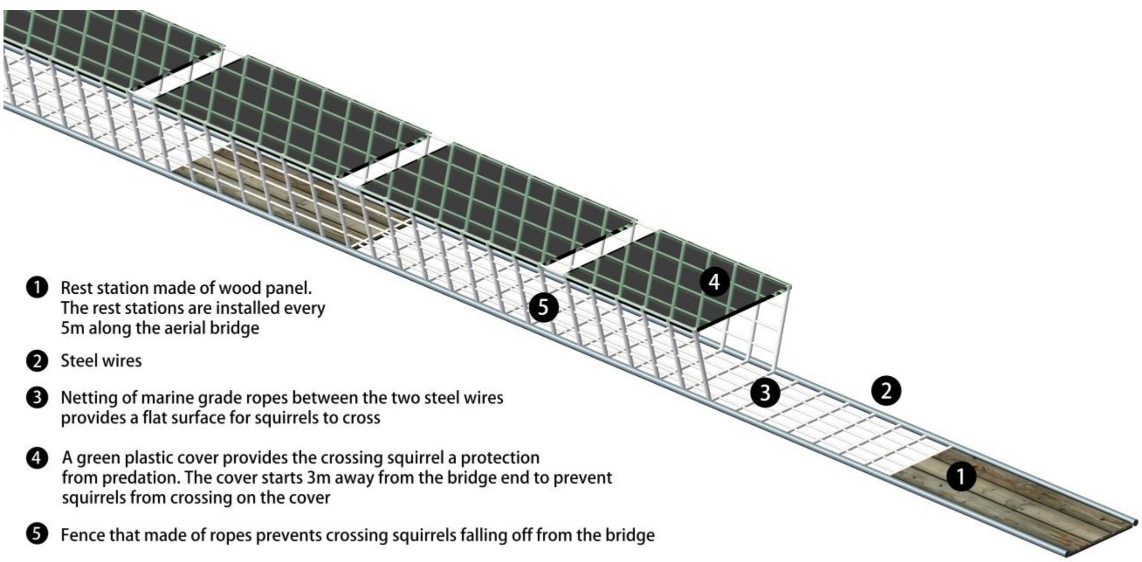

Figure 6.11: Aerial Bridge Design
Source: Prepared by the author.

- Design a cover to provide protection from predation (Ball and Goldingay, 2008).

- A web of aerial bridges should extend from all mature home trees to roadside trees or poles and into the canopies of trees in adjacent land patches. The end of the bridge web should be attached to *S. carolinensis*'s home trees if possible, while all the home trees which are mature and healthy in an area should be included in the bridge web. A single rope (manila, hemp, polypropylene, and hempex are all suitable materials) or liana, 15–30 mm in diameter, is sufficient to connect trees on the same side of the road (RSNE, 2016).

  This web of bridges is installed to guide *S. carolinensis*'s movement. The bridges serve as guiding paths to the road-crossing structure. Single-rope and single-pole overpasses in the web are not needed to be designed as stable as the road-crossing bridge.

  Figure 6.12 and Figure 6.13 give an example of an aerial bridge web design.

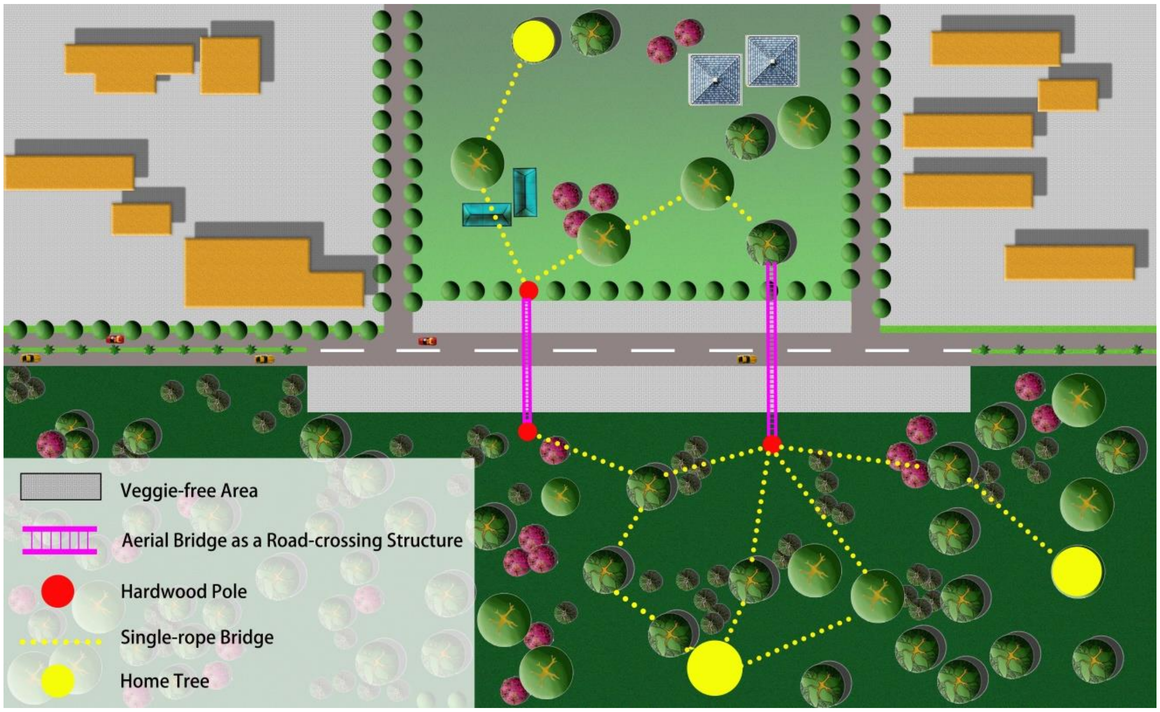

Figure 6.12: Site Plan for an Aerial Bridge Web
Source: Prepared by the author.

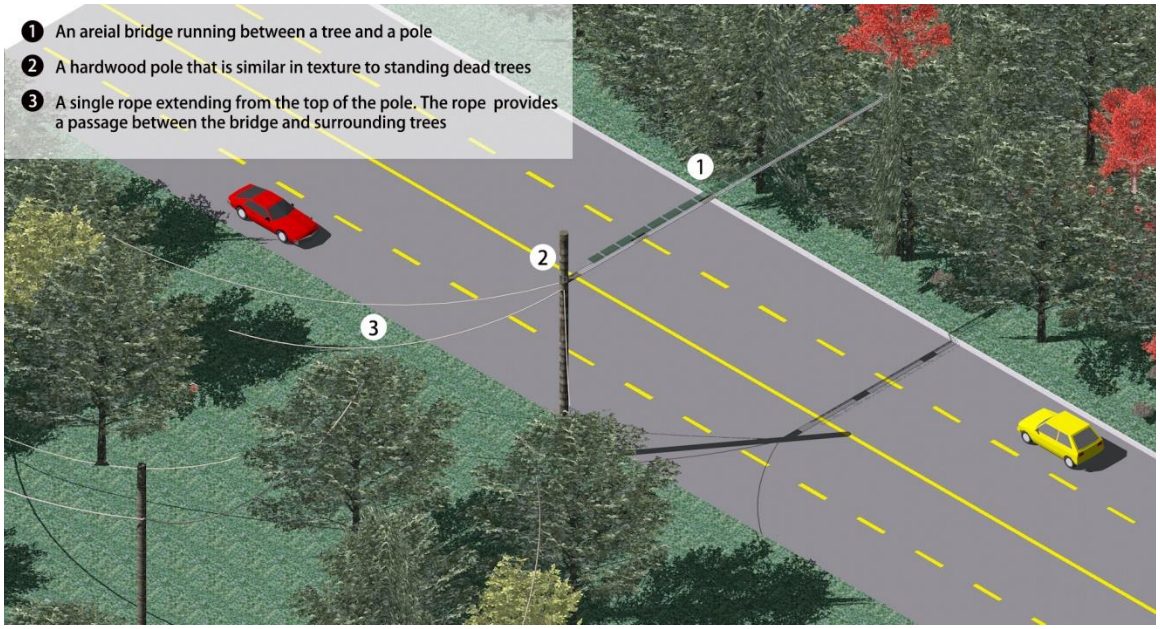

Figure 6.13: 3D View of an Aerial Bridge Web
Source: Prepared by the author.

- Take advantage of existing power poles when constructing the bridge web. When mature trees are absent at important points of the web, or if the roadside home trees need regular trimming in a district, a pole is required. Poles should be more than 30 cm in diameter and buried 1.5 m into the ground. Hardwood poles are similar in texture to standing dead trees, which are regularly used by *S. carolinensis* (Ball and Goldingay, 2008; RSNE, 2016).
- A fence or clearance of roadside vegetation should be implemented in association with aerial bridges. As stated before, roads with a verge wider

than 10 m had fewer WVCs than roads with close vegetation. These measures will discourage *S. carolinensis* from crossing on the ground.

(b) Underground tunnels

An underground passage or tunnel may also be used as a crossing structure. Because most WVCs occur in fragmented landscapes, underground tunnels are an appropriate option for squirrels, with their small body sizes. Squirrels have been observed using under-road tunnels to cross roads (Plante *et al*., 2016; Puig *et al*., 2012).

Retrofitting existing underground infrastructures such as drain pipes or stream culverts as *S. carolinensis* passages is an easy way to construct a squirrel tunnel. Any existing tunnel with an opening larger than 130 by 130 mm can be used by *S. carolinensis*[17]. There are reports of *S. carolinensis* swimming, thus occasional water will not prevent them from using a culvert. Plante *et al.* (2016) reported that a wooden ledge extending from a culvert can help *S. carolinensis* to find and use the passage. Positioning a wooden or rock ledge on one side of a tunnel or culvert is suggested to facilitate use. The ledge does not need to be attached to the wall.

Intentionally designed squirrel tunnels are needed when there are no existing underground tunnels in the area. A squirrel tunnel implementation should adhere to the following guidelines:

- Use wood or stone in the underground passage to simulate a natural environment; leaves can be laid on the ground surface to encourage use

[17] 130 by 130 mm is the smallest dimension of a squirrel trap.

- Tunnel height should be 300–500 mm, and width should be 250–350 mm; in districts where the average body size of *S. carolinensis* is larger, a larger tunnel should be used
- Feeders should be installed at either end of the tunnel, and replenished regularly to encourage use, especially in the first months after installation
- Keep the road verge near the tunnel clear of vegetation, or convert the verge to gravel or other non-vegetative surface to encourage squirrels to seek an alternative crossing method

(7) Exclusion fences

A seasonal exclusion fence is suggested at WVC hotspots in autumn, when *S. carolinensis* spends a large amount of its time on the ground. Design principles for a seasonal exclusion fence include the following:

- Materials with smooth and solid surfaces such as rigid plastic or polythene are recommended to block squirrels from roads, because they can climb; but a mesh fence made of thin plastic has been proven effective in practice (Fogle, 2014). You should specify larger grid size for these plastic fences. They are notorious snake killers when the grid size is large enough for the snake’s head to move through, but not large enough for the rest of the body. The snake becomes trapped and starves to death.

Figure 6.14: Thin-Plastic Mesh Fence
Picture Source: http://www.hobbyfarms.com/a-cheap-way-to-keep-squirrels-out-of-your-garden/.

- The fence should be installed at least 2 m away from the nearest plantings to prevent *S. carolinensis* from leaping over the fence
- Because *S. carolinensis* is a good digger, bury the fence 50 cm into the ground, with a right angle bend toward the field at the bottom
- Fence height should be at least 2 m (SFGATE, 2016)

(8) Monitoring

Monitoring crossing use supplies important information for maintenance, modification, evaluation, and further implementation. Monitoring a single constructed crossing structure for a short duration enables evaluation of the results. The time needed for squirrels to adapt varied widely among sites, with one squirrel bridge was not used until 11 months after construction. A monitoring period of at least two years is recommended to allow *S. carolinensis* to habituate to the crossing structures (Soanes and van der Ree, 2008). There are multiple monitor methods, including the following

- Hair tubes set at the ends of the bridge (RSNE, 2016). Some hair tubes have glue muff at entrance and exit, or a sticky patch which placed inside the tube to catch hair from any animal that enters the tube. This hair can then be DNA tested to confirm how many individuals has used the bridge.
- Remotely triggered, infrared, 24-hour cameras at either end of the crossing with infrared beam sensors placed every one to four meters along the crossing enable a series of consecutive photos, stamped with date and time, to record an animal's crossing (Soanes and van der Ree, 2008; Yokochi and Bencini, 2015).
- Identification of some individuals with unique markings (e.g., ear notches) can confirm regular and repeated use of the crossings.

The evaluation of the presented plan options is shown in Figure 6.15.

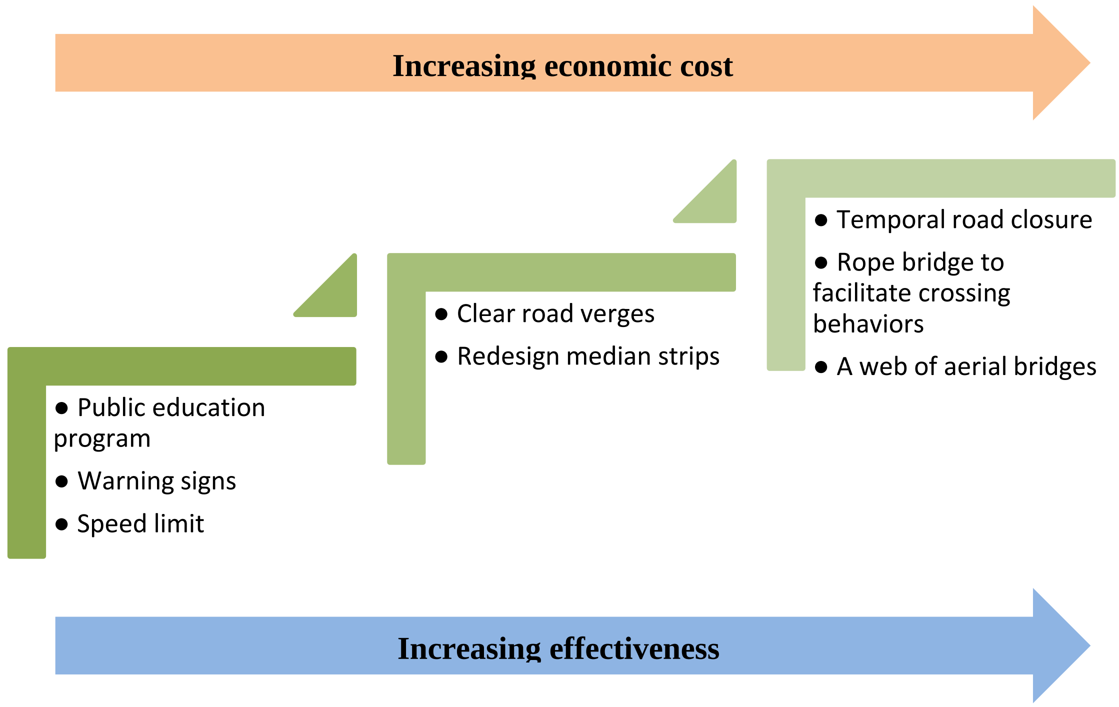

Figure 6.15: Evaluation of The Presented Plan Options
Source: Prepared by the author.

The decision-making process is shown in Figure 6.16.

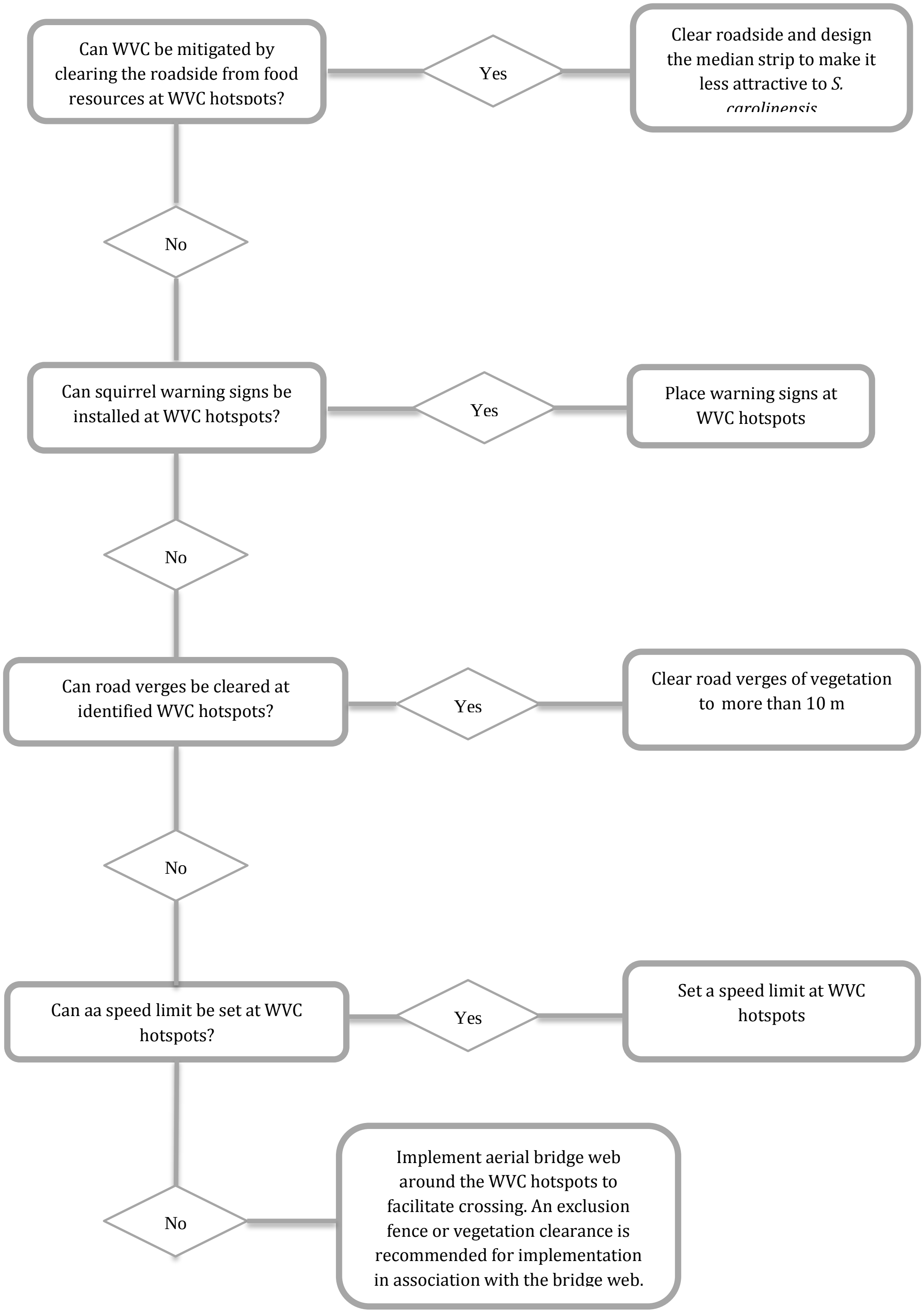

Figure 6.16: Decision-making Process on WVC Mitigation Measures for *S. carolinensis*
Source: Prepared by the author.

6.3 House Sparrow (*Passer domesticus*)

6.3.1 Basic biology

P. domesticus is a small bird with a typical length of 14–16 cm, wingspan of 19–25 cm, and mass of 24–38 g (Brazil, 2009). *P. domesticus* is native to Europe and Asia, and is now introduced to most parts of the world. It is the most widely distributed wild bird on the planet and most often in conflict with people (Hadidian, 1997; Royal Society for the Protection of Birds [RSPB], 2015). Most members of this species are non-migratory. *P. domesticus* has a long history of coexistence with humans and is rarely found away from villages, towns, or cities. It lives in settings ranging from isolated rural farms to urban centers (Brazil, 2009; Encyclopedia of Life, 2016).

P. domesticus has an extremely large range and is listed as least concern on the IUCN Red List (IUCN, 2016c; Seress *et al.*, 2012). However, according to provisional data for 21 countries from the Pan-European Common Bird Monitoring Scheme, *P. domesticus* population has been undergoing a moderate decline since the early 1980s in several parts of the globe (Seress *et al.*, 2012). The population loss in major urban areas has been even more pronounced, amounting to 85–98.8% during the last 20–40 years (Anderson, 2006; Seress *et al*., 2012). There is no consensus on a possible cause. Numerous hypotheses have been put forward, and several mention traffic. As Bergtold (1921) stated, not only did the replacement of the horse by motor vehicles remove a great source of food from the sparrow,[18] but the faster moving traffic made the streets less safe to feed in and were presumably responsible for a disproportional mortality of the naïve young birds (Bergtold, 1921; Heij and Moeliker, 1986).

6.3.2 *P. domesticus* and WVC

Birds are addressed as important victims in most multiple taxa WVC studies (Jacobsen, 2005). Unsurprisingly, as a bird that is tightly linked to humans, *P. domesticus* is frequently involved in WVCs. In most research on *P. domesticus* population decline, WVC is not identified as a dominant factor, but WVC does outrank many other sources of direct anthropogenic mortality such as predation by outdoor domestic cats or collisions with buildings (Coffin, 2007; Loss *et al.*, 2014). Some studies assert that the negative impact of WVC mortality is seriously under-estimated (e.g., Moller *et al.*, 2011). In England, 13% of the *P. domesticus* population was killed by WVC in 1960–1961 (Hodson and Snow, 1965); A German study undertaken during 1973–1976 found that about 5% of the local *P. domesticus* population were killed in WVC. It was also found that nearly all *P. domesticus* juveniles are killed by vehicles near Copenhagen, Denmark (Erritzoe *et al.*, 2003). This passerine is involved in WVC more commonly than others in the genus (Dunthorn and Errington, 1964; Erritzoe *et al*., 2003; Hodson, 1960; Peris and Pescador, 2004), although always in numbers lower than those seen for non-

[18] Spillage from horse nosebags and undigested seeds in their droppings were essential sources of food for *P. domesticus* (Bergtold, 1921; Summers-Smith, 1963). Replacement of horses by cars had a negative effect on the food supply of house sparrows (Anderson, 2006).

passerines, such as barn owls (*Tyto alba*) or nightjars (*Caprimulgus spp*) (Peris and Pescador, 2004). The following are some biological characteristics that lead house sparrows to become WVC victims:

- Small body size and gray coloration make *P. domesticus* hard to detect by divers, especially in low-light environments.
- This bird prefers habitats in human settlements, so its flight routes frequently intersect with roads. According to Erritzoe *et al*., 2003, territories 150–200 m from the road are risk zones for small birds. About 5% of the *P. domesticus* population lives in this WVC risk zone.
- *P. domesticus* is not shy and thus may react less when a car appears (Erritzoe *et al*., 2003). Its ability to learn to cope with the danger of traffic is weak.[19] But also there is research shows that urban *P. domesticus* may learn to deal with vehicles as a result of dense traffic (Odzuck, 1975).
- *P. domesticus* frequently visits roads.
- *P. domesticus* forages in flocks during the non-breeding season. When flocks are alarmed it can take a long time for them all to cross a road to safety (Erritzoe *et al*., 2003).

Somewhat surprisingly, the patterns of WVC for *P. domesticus*, or for birds in general, are not well addressed in research. As a consequence, only a few characteristics of *P. domesticus* WVCs could be identified:

[19] Some authors have stated that there does not yet appear to be any sign of traffic awareness among most species of birds. They cannot recognize traffic as a potential danger even though they have experienced many WVC casualties (Dunthorn and Errington, 1964).

- Juveniles are more frequent WVC victims than adult birds[20] (Erritzoe *et al.*, 2003; Loss *et al*., 2014; Robinson *et al.*, 2005). There is logical and experimental evidence supporting this conclusion. Juveniles do not yet have full flight capabilities and lack experience in dealing with oncoming vehicles. In Denmark, 72% of WVC victims in August were young birds (Erritzoe *et al*., 2003). In Russia, 50–90% of all birds killed on roads between April and October are young birds (Hansen, 1969, 1982).
- Most WVCs happen in spring and summer. This peak is connected with two activities: the first is breeding activities and reduced attention to surroundings; the second is dispersal and inexperience of young birds (Erritzoe *et al.*, 2003). Also, the summer harvest is an important factor in WVCs. In summer, cereal seeds, growing corn, and other crops attract birds to fly across roads (Erritzoe *et al.*, 2003).
- Daily WVC peaks occur at about 12:00 (Erritzoe *et al.*, 2003), which may relate to frequent human activity at that time.
- Smaller roads in rural area present a greater danger to birds, because the birds there are not familiar with traffic (Odzuck, 1975).
- Road characteristics, such as speed limit, traffic density, or roadside plantings, have substantial influence upon *P. domesticus* WVC (Erritzoe *et*

[20] Erritzoe *et al.* (2003) raise questions about this conclusion due to the time restriction on determining ages of WVC victims. It is only during or just after the breeding season that age research can be done. At this time, young birds appear in great numbers and differ significantly in plumage from the adults. During the late autumn and wither, after moulting, it is not possible to distinguish between young and mature house sparrows without an internal inspection of the gonads.

al., 2003).WVCs are rare on roads with a speed limit below 40 km/h, and start to increase at a speed of 56 km/h. Nevertheless, evidence shows that even a lower speed can be fatal to *P. domesticus* (Erritzoe *et al*., 2003).

The current knowledge regarding bird WVC mitigation measures is not fully developed. There are numerous literature citations about the impacts of roads on birds, but only a few offer suggestions for mitigation or review the effectiveness of the relatively few existing mitigation measures (Jacobson, 2005; Zuberogoitia *et al*., 2015). After identifying WVC hotspots, mitigation suggestions for birds include reducing speed limits, erecting signs to alert drivers, and placing flight deflectors along roadsides to force birds to fly above vehicle height (Bard *et al*., 2001; Gomes *et al.*, 2009; Loss *et al.*, 2014; Ramsden, 2003). van der Ree *et al.* (2009) recommended that WVC mitigation for flying birds should be similar to that for bats and butterflies.

Most of these suggestions have not been put into practice. WVC mitigation measures for birds are not implemented as widely as for mammals. There are hardly any WVC mitigation projects for *P. domesticus* worldwide. There are a number of reasons for this. (a) *P. domesticus* WVCs normally do not induce serious human injury or financial losses. (b) *P. domesticus* is so abundant that it is beyond the reach of conservation bodies, and WVC mortality does not impose a significant impact on the local population. In addition, *P. domesticus* traditionally has been misidentified as a pest to agriculture. In areas where it has been introduced, *P. domesticus* is cited by some as the reason for population declines of some native bird species.[21] Its invasive nature often gives it an unpleasant association (Bell, 2011; The Humane Society of the United States, 2012). (c) Most research on bird victims of WVC is conducted by ornithologists. Their research presents counts of WVC victims and describes the effect of WVC on avian mortality, while lacking analysis of the results or suggestions for mitigation (Erritzoe *et al*., 2003; Moller *et al*., 2011). (c). (d) Mitigation measures for birds, especially for those like *P. domesticus* with low, erratic flight patterns, are not as widely developed or deployed as for large mammals. This phenomenon is largely because birds' ability to fly renders nearly all these safeguards superfluous (Erritzoe *et al*., 2003).

The magnitude of *P. domesticus* mortality in WVCs highlights the need for mitigation measures. Both research and practice need be further developed. Increased attention should be given to documenting which regions are most vulnerable to *P. domesticus* WVC, and to research on mitigation measures.

6.3.3 *P. domesticus* ecology and WVC mitigation suggestions

Table 6.4 *P. domesticus* Ecology and WVC Mitigation Suggestions

	Behavior	**WVC Mitigation Observations and Suggestions**
Reaction to Roads	Sparrows have high tolerance for traffic noise (Peris and Pescador, 2004). *P.*	*P. domesticus* shows no obvious avoidance of roads,

[21] However, this idea is not proven, and is doubted by many (The Humane Society of the United States, 2012).

	domesticus forages near roads and nests in roadside trees (Gilbert, 1989).	and is therefore highly susceptible to WVCs.
	P. domesticus is more abundant near high traffic roads with concentrated human activities (Peris and Pescador, 2004). Busy routes where there are lay-bys or bus stops with litter bins are worked over by house sparrows (Gilbert, 1989).	Bus stations, train stations, and open-air restaurants in urban area are potential WVC hotspots. A fence should be installed near stations to increase flight height and prevent *P. domesticus* from flying into roads In suburban and rural areas, roads running through agricultural land are putative WVC hotspots.
	Increased traffic speed and volume lead to high WVC mortality (Loss *et al*., 2014).	Traffic calming may be implemented at *P. domesticus* hotspots.
	When sparrows forage in flocks on roads, their escape flights may take a longer time; and juveniles react more slowly.	Clearing food resources from roads and roadsides to prevent *P. domesticus* from flying into the road.
	Most WVCs occur on the verge of roads due to lack of good sightlines (Dunthorn and Errington, 1964).	Wider, straighter roads have fewer WVCs.
	WVC mortality rates are higher for juvenile birds because they lack experience.	Fledglings need special attention in WVC mitigation strategy development. WVC mitigation measures should be taken during nesting

		season.
	During fledging season, sparrow parents continue to feed their young. (Arnold, 1992). *P. domesticus* parents are found to feed their fledglings on roads.	Strict regulations or rules are needed to mitigate WVC during this season.
Life Cycle	Breeding season varies geographically. Residents in temperate latitudes have a single reproduction season that extends from early or mid-spring through late summer; in tropical or subtropical areas, clutch initiation has been reported in every month of the year, but there are two peaks of clutch initiation: one preceding and one after the summer rainy season (Anderson, 2006; Arnold, 1992).	WVC mitigation implementation needs to consider the local context; mitigation measures should be enhanced for fledglings.
	When *P. domesticus* chicks are 14–17 days old, they are fully fledged and ready to leave the nest (Arnold, 1992). Fledging and juvenile *P. domesticus* have high mortality rates. Most fledglings leave their nests in summer (Gurney, 1896).	Fledging birds are especially vulnerable to WVC. Roadside trees with sparrow nests need special mitigation attention.
	Each nestling can consume as many as 3,000 to 4,000 insects during its first month (Dixon, 2010). As growing young chicks need constant feeding, the parents make as many as 300 trips a day to the nest with food (Arnold, 1992).	The frequent trips increase the possibility that the parent will be involved in a WVC. In summer, attractive foraging areas for *P. domesticus* include agricultural and garden areas to find caterpillars, Japanese

		beetles, aphids, cutworms, army worms, and locusts; water areas for water-beetles (Anderson, 2006); and roadside or median green belts where numerous insects are found. During spring, roadside lands and nests have high potential to become WVC hotspots. Vegetated areas in the middle of the road or along the roadside are attractive to *P. domesticus*, especially in spring and summer. Flight diverting measures should be implemented at these times.
Foraging pattern	Vegetable material comprises more than 90% of *P. domesticus* annual diet. Animal food occurs in the diet primarily during the breeding season, peaking in summer due to the egg-laying females need high protein and nutrient demands of egg formation (Anderson, 2006). Also the insects are needed in the followed feeding activities by the *P. domesticus* parents.	In summer *P. domesticus* needs more insects as food. Gardens or vegetation attract *P. domesticus*.
	P. domesticus has a robust immune system. Its foraging behavior is extremely opportunistic. They occasionally feed on	Clear roads and roadsides from attractions for sparrows, including food and water.

	discarded food and refuse, even on roadkill carcasses (Dixon, 2010; Gavett and Wakeley, 1986). Garbage containers, outdoor restaurants, and other establishments with leftover food and crumbs are attractive sites for sparrow flocks (Anderson, 2006).	Set strict rules for seed transportation. Roadside trash cans should have special designs to keep *P. domesticus* away from roads.
	P. domesticus forages on the ground, in trees, and on shrubs. Occasionally it catches insects in the air.	Manage road and roadside vegetation.
	The house sparrow's ground-foraging behavior usually occurs in open, exposed areas (Anderson, 2006), which may increase the probability of early detection of an approaching predator.	Roads with concealing vegetation inhibit birds from foraging in flocks. Design concealing vegetation for WVC hotspots to prevent birds from staying for long.
	House sparrows visit open-air restaurants to forage on leftovers and dropped crumbs. (The Humane Society of the United States, 2012).	When open-air restaurants are located near roads, efficient clean up, trash removal, and fencing around trash receptacles will discourage sparrows. Remove inviting nesting sites around restaurants.
	Although sparrows are opportunistic, oats, wheat, millet, sorghum, and cracked corn are favorite foods. In suburban areas, sparrows are most abundant near wheat-growing farms. Roads running through the	Road stretches running through oats, wheat, millet, sorghum, or corn fields are putative WVC hotspots.

	wheat fields offer a greater variety of food. e.g., spilt grain after harvest (Anderson, 2006; Erritzoe *et al.*, 2003).	
	Research on sparrows in Hamburg, Germany, found that 54% of adult sparrow food was provided directly or indirectly by humans; it consisted primarily of wild bird seed and human refuse (Kelting and Laxson, 2010).	Reduce feeding opportunities along roads in urban area.
	Salt used to de-ice roads in winter attracts *P. domesticus*. *P. domesticus* flocks are commonly struck by vehicles as they consume salt in roadways (Kelting and Laxson, 2010; Mineau and Brownlee, 2005). They consume salt to fill a physiological need and to provide grit to the gizzard and the crop. Road salt consumption not only leads to an increase in WVC mortality, but also causes salt toxicity (Kelting and Laxson, 2010).	Set traffic calming measures and warning signs when large flocks of *P. domesticus* are observed consuming salt on a specific road stretch.
	After rainfall, earthworms in the soil may be washed onto roads. In damp weather, more earthworms come to the surface. The heat of the road attracts many insects and many birds that forage on them (Erritzoe *et al.*, 2003).	In sensitive area for *P. domesticus* WVC, set barriers around median strips with large earthworm populations.
	P. domesticus tends to stay low and will be attracted to food sources on the ground. Water or food that is near suitable shelter	Hedgerows along roads or in the median, roadside plantings, or buildings all

	such as a low shrub or dense thicket is most attractive. Vigilance increases with distance to protective cover (Anderson, 2006).	serve as protective cover.
	P. domesticus use sprinklers and water fountains as a source of water.	When *P. domesticus* activity is frequently observed around an existing water sprinkler, set barriers around it.
	Foraging activity peaks immediately after sunrise, followed by a decline in feeding activity until shortly before sunset, when a second peak occurs.	Include information about sparrow foraging times in driver education programs and public awareness campaigns.
	Nocturnal foraging occurs when *P. domesticus* feeds on insects attracted to lights (Anderson, 2006.	Street lights attract sparrows.
	Grit with diameters ranging from 0.1–2.4 mm, colored green, white, or yellow are attractive to *P. domesticus*. Grit is a prominent component of *P. domesticus* diets that aids mechanical break-down of food in the ventriculus (Anderson, 2006).	Set strict restrictions on road transportation to avoid leakage of grit from containers during transportation.
Habitat	The only habitats where the house sparrow is not found are dense forest and tundra.	Roads running through dense forest are unlikely to induce WVCs.
	In warmer areas, *P. domesticus* may build its nests in the open, on the branches of trees, especially evergreens and hawthorns. Cavities and holes are preferred for nest	Prevent sparrows from nesting in traffic infrastructures on roads. Design these infrastructures

	sites in cold weather. *P. domesticus* nests most commonly in holes or crevices in buildings or other human structures, in vines on the exterior walls of buildings, in holes in trees, and in nest boxes. The backs of highway signs, billboards, and traffic lights are all potential nesting sites (Anderson, 2006; Arnold, 1992).	like bridges or street lights near or on roads without platforms, cavities, crevices. Build nest boxes for *P. domesticus* in areas far away from roads to prevent them from using traffic infrastructure for nesting. Roadside trees with sparrow nests need special attention.
	Nest height varies from 1.5–32 m, most of which fall in the 3–5 m range (Anderson, 2006).	Artificial *P. domesticus* nest boxes should be set at 3–5 m heights.
	P. domesticus has loose colonies with central nesting sites. Peripheral sites are located within 25 m of the colony center (Summers-Smith, 1963).	In suburban areas, bird houses designed for *P. domesticus* nests should be set at least 25 m away from roads to keep flocks from roosting on the roadside.
	P. domesticus strongly prefers to nest within 400 m of buildings (Anderson, 2006; The Humane Society of the United States, 2012).	Set bird houses near human dwellings to improve nest box occupation.
	A national survey of nesting opportunities for *P. domesticus* in buildings found that they were much more likely to nest in older buildings (pre 1919) and in more recent buildings (pre 1965) if they had not had roof repairs, which reduce access to eaves	Road segments with old buildings on either side may be frequently visited.

	and roof spaces for nesting birds (Robinson *et al.*, 2005).	
Flight pattern	*P. domesticus* flies straight and fast. Due to their preference for feeding on the ground, they do not fly high. Their habit of flying in compact flocks at no great height leads to them being WVC victims (Dunthorn and Errington, 1964).	This flight pattern means *P. domesticus* is commonly involved in WVCs. Regular flight diverting measures do not work well for them.
	As flocking birds, *P. domesticus* may not be able to easily fly between a food source and shelter.	Flock foraging increases the possibility of involvement in WVCs. Special attention should be paid when large flocks are observed.
	P. domesticus forage primarily within a 2-3 km radius of their feeding and roosting sites during most of the year (Anderson, 2006). In late summer and autumn, flocks move regularly from their roosting sites in urban and suburban areas to grain fields (North, 1968, 1973).	When grain/wheat fields are located within 3 km of urban/suburban areas, daily movement between roosting and foraging sites occurs in late summer and autumn. Putative WVC hotspots occur where flight routes cross roads. WVC mitigation measures need to be in late summer and autumn.
Social behavior	Sparrow flocks engage in social activities such as dust, mud, or water bathing to remove lice and other tiny insects that sometimes live on their skin or feathers. They may drink from and bathe in puddles	Clear roads and roadsides of puddles and sand piles in sensitive areas for WVCs.

	along or on roads (Anderson, 2006; Arnold, 1992; Erritzoe *et al*., 2003)	
	Social foraging is a common feature among sparrows. In late summer and through the fall and winter, *P. domesticus* gathers in large flocks of up to several hundred. During the day they forage and at night they roost in trees and on buildings.	This foraging pattern makes *P. domesticus* populations easy to observe in an area. As a result of its erratic flight pattern, areas where large flocks are observed are sensitive areas for WVCs.
	Large flocks are often observed near grain fields at harvest time and usually include many juveniles (Anderson, 2006).	Roads running through or near grain fields in late summer and autumn need special attention.
Others	Buildings or trees that are 20–25 feet high are the favorite cover for *P. domesticus* whenever danger, real or imaginary, threatens (Dunthorn and Errington, 1964).	With food resources on one side and 20–25 feet high buildings or trees on the other, *P. domesticus* may fly back and forth continually, creating a WVC hotspot.

6.3.4 Suggestions for *P. domesticus* WVC mitigation strategy development

Most WVC mitigation measures (e.g., excluding fences and crossings) that have been widely applied for mammals will not work for wide-ranging birds with an ability to fly. Current WVC mitigation measures for birds are developed for species with direct, rapid flight, not for species with small body sizes and slow or meandering flight patterns, such as *P. domesticus* (Kociolek *et al*., 2015). WVC mitigation measures for this species are restricted to changing human behaviors or preventive measures. Kociolek *et al*. stated that “the best practice of bird conservation along roads is to avoid attracting birds to the road or roadside…” (Kociolek *et al*., 2015, p. 287).

6.3.4.1 Data collection

There are two methods to track *P. domesticus* WVC victims: public reporting systems and field surveys. A field survey consists of patrolling potential WVC hotpots on foot once every 24 hours to look for *P. domesticus* carcasses. Patrolling should occur in late summer and autumn when *P. domesticus* are more active and juvenile populations are higher than usual. A field survey also can locate *P. domesticus* nests in roadside trees and buildings during nesting season.

P. domesticus victims of WVCs are easily under-estimated even if data collection is actively pursued. This bird is too small to induce an accident, and their carcasses are not easily noticed before they begin to decompose. In addition, scavengers pick up small bird carcasses rapidly, often within minutes (Jacobson, 2005). WVC mitigation strategies should be initiated before an alarming number of victims has been reached.

As a result of their erratic flight patterns, it is not easy to define WVC hotspots for *P. domesticus*. Evidence has shown, however, that the frequency of finding a particular species as WVC victims is connected with its population density in the surrounding landscape (Erritzoe *et al.*, 2003). From this perspective, special attention should be given to areas where large flocks have been observed. Information should be collected from local experts, residents, and local research departments.

In areas where large sparrow populations have been observed, the following locales may become WVC hotspots for *P. domesticus*:

- Bus or train stations along road
- Open-air restaurants near roads, where leftovers and dropped crumps are attractive food sources
- Open trash along roads
- Road segments with trees and old buildings (pre 1965) without roof repairs
- Road segments with hedgerows on roadsides or with a vegetated median that may harbor insects and produce seeds
- Road segments with food resources on one side and 20–25 feet high building or trees on the other, between which *P. domesticus* may fly back and forth continually
- The verges of road segments where *P. domesticus* lacks good lines of sight
- Areas around streetlights during summer when *P. domesticus* parents need to forage for animal food to feed their nestlings, because streetlights attract large numbers of insects

- In suburban and rural areas, road segments running through farmland, fruit orchards, or heavily vegetated areas (Erritzoe *et al.*, 2003); grain fields near harvest attract large *P. domesticus* flocks with many juveniles
- Where roads are at the same level or higher than surrounding areas, birds fly low to the road surface when crossing the road
- *P. domesticus* forages close to roosting sites except in late summer and autumn, when large flocks move regularly from roosting sites to grain fields; sometimes crossing roads. WVC mitigation measures need to be taken at such times (see Figure 6.17 for an example):

Figure 6.17: Using the Maximum Flight Distance to Define WVC Hotspots
Adapted from photo sources: Google Maps**.**

- If the road is at the same level or higher than the surrounding area, birds crossing the road will fly low to road surface and are more possible be killed in WVC.

- Two subspecies of HS, *P. D. bactrianus* (which breeds in the Central Asia) and *P. D. parkini* (which breeds in Kashmir, Nepal) are migratory in large flocks and they tend to use the same route year by year. When their migration route crosses with roads, WVC may occur.

6.3.4.2 Plan action options

Evidence has shown that young birds are especially fragile to WVC due to lack of experience, and because parents feed them on roads. Planned mitigation actions should be enhanced for *P. domesticus* fledglings and juveniles. According to Seel's (1968) research, fledgling populations reach a peak 3–5 weeks after the summer solstice. Surviving fledglings grow to be juveniles, and the juvenile population peaks in late summer and autumn, which is also the peak time for *P. domesticus* WVCs (Loss *et al.*, 2014).

As stated before, mitigation measures are mainly preventive or focus on changing human behavior.

(1) Public education programs.

Raising public awareness of the following issues may contribute significantly to *P. domesticus* WVC mitigation:

- Locations where large flocks have been observed
- Peak times for foraging activity—immediately after sunrise and shortly before sunset
- Reducing feeding opportunities on roads
- Reducing speed limits when large *P. domesticus* flocks are observed

(2) Clear roads and roadsides of feeding and nesting opportunities to discourage *P. domesticus* from spending time near or on roads. Birds are more likely to collide with traffic when they forage, roost, or nest near roads (Zuberogoitia *et al*., 2015).

- Clean up open-air restaurants along roads and erect protective barriers to make the birds fly higher to avoid traffic
- Build barriers around open trash cans or water sprinklers, especially those near open-air restaurants and transportation stations.[22] Poles or wider posts that produce the illusion of a solid barrier can be used instead of a wall. Install flags on the barriers to increase visibility and prevent birds from flying through the barriers, although the effectiveness of this measure is unknown (Erritzoe *et al.*, 2003; Kociolek *et al*., 2015; Zuberogoitia *et al*., 2015). See Figures 6.18, Figure 6.19 and Figure 6.20 for examples.

[22] Buildings or trees 20–25 feet high are favorite cover for *P. domesticus* (Dunthorn and Errington, 1964). So the height of protective cover is set as 20 feet for the barrier design in this research.

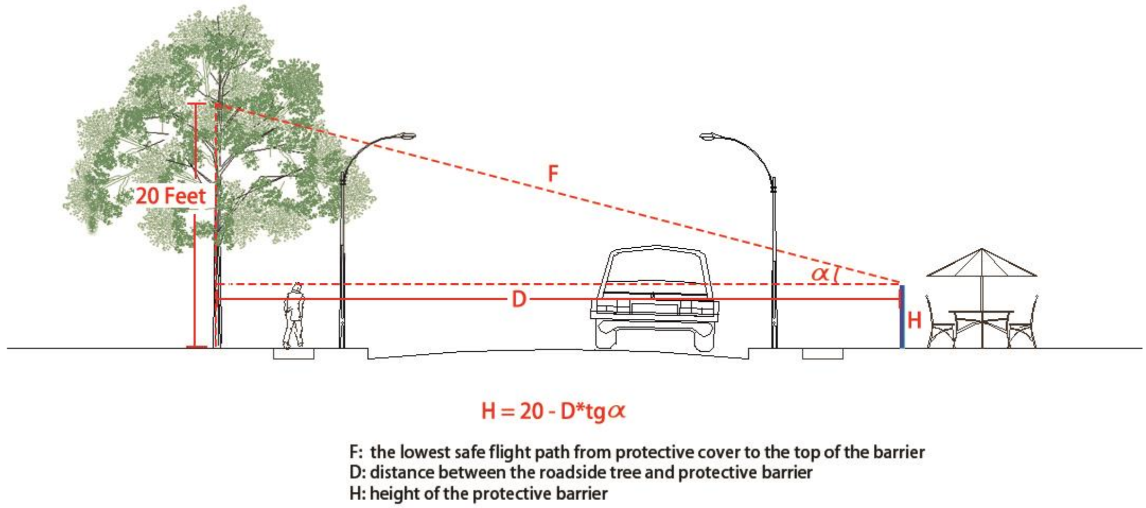

Figure 6.18: Height of Barrier for an Open-air Restaurant on a Road without a Median
Source: Prepared by the author.

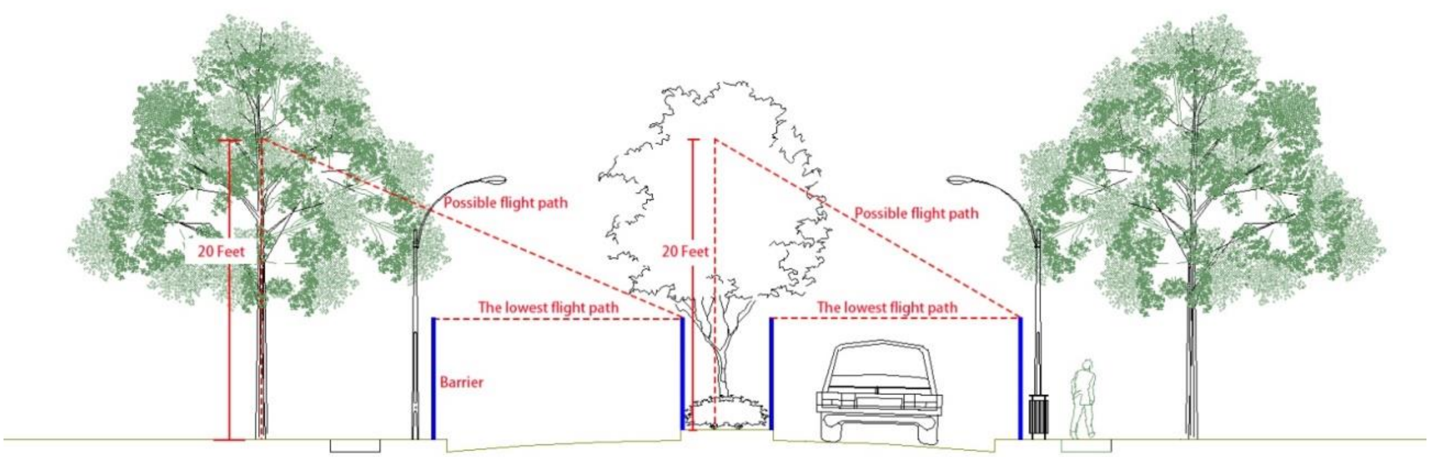

Figure 6.19: Height of Barrier for a Median Strip and Trash Bins
Source: Prepared by the author.

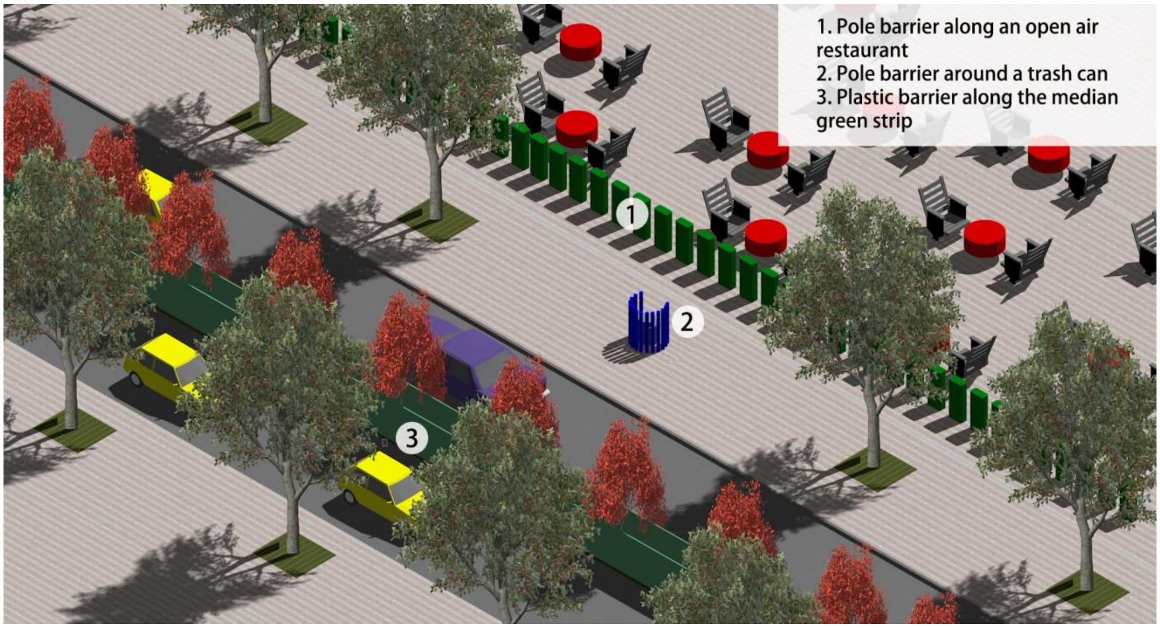

Figure 3.20: 3D View of Barriers for a Road with Open-air Restaurant, Trash Bins, and a Median Strip
Source: Prepared by the author.

(3) Manage roads, medians, roadside greenbelts, and vegetative cover to reduce their attractiveness to *P. domesticus*. There are two approaches to achieve this end. First, construct barriers. *P. domesticus* needs more insects as food in summer, so the barrier could be installed in summer, and removed during autumn and winter. Vegetated areas that produce seeds and harbor insects (caterpillars, Japanese beetles, aphids, cutworms, army worms, and locusts) are attractive to *P. domesticus*, especially in spring and summer. Second, avoid planting species that provide resources (e.g., insects, seeds, fruits) to make roadsides and medians less attractive to birds. The attractiveness of roadsides and verges can be reduced by modifying maintenance programs (Kociolek *et al*., 2015). Exotic, ornamental, or evergreen

plants harbor less insect fauna and limit the availability of food for *P. domesticus*, so they are recommended for median strips (Arnold, 1992; Seress *et al*., 2012). In some cases, it may be appropriate to convert the verge to gravel or another non-vegetative surface (Kociolek *et al.*, 2015).

- Remove bird breeders or feeding stations from roadsides, roofs of adjacent buildings and gardens which are near to roads, especially in late autumn and winter when *P. domesticus* regularly uses feeders
- Remove puddles on roads and avoid placing fountains near roads because *P. domesticus* frequently drinks from sprinklers, puddles, or fountains
- Clear sand from roads to prevent *P. domesticus* from staying on the road
- Enact strict regulations for road transportation should be to avoid leakage of grain and grit on roads
- Erect barriers around medians in WVC hotspots with moist climates and large earthworm populations; after rain or in damp weather, earthworms come to the surface and may attract *P. domesticus*

(4) Naïve *P. domesticus* fledglings are especially vulnerable to WVC. Remove inviting nesting site along roads to reduce the possibility of fledglings encountering vehicles.

- Close cavities and cover vents on the outer walls of buildings that face roads (The Humane Society of the United States, 2012; see Figure 6.21). What should be mentioned here is that when these nesting opportunities along roads are removed, place artificial nest boxes at least 50 m away from roads to supply safe nesting sites for *P. domesticus*

Figure 6.21: Vent Cover
Source: The Humane Society of the United States.

- Avoid hollow cross poles for traffic lights, street signs, or billboards, or ledges under the eaves of buildings and railway station platforms, and install covers on existing holes (Arnold, 1992)
- Mow road verges regularly to reduce their attraction for *P. domesticus*; mowing should occur in non-nesting season to avoid killing eggs, fledglings, or adults (Kociolek *et al*., 2015; Jacobson, 2005)
- Set artificial *P. domesticus* nests at least 25 m away from roadsides to keep the flocks roosting on the same side of the road, because peripheral

nest sites are located within about 25 m of the colony center; set the bird houses within 400 m of buildings to improve occupation (see Figure 6.22)

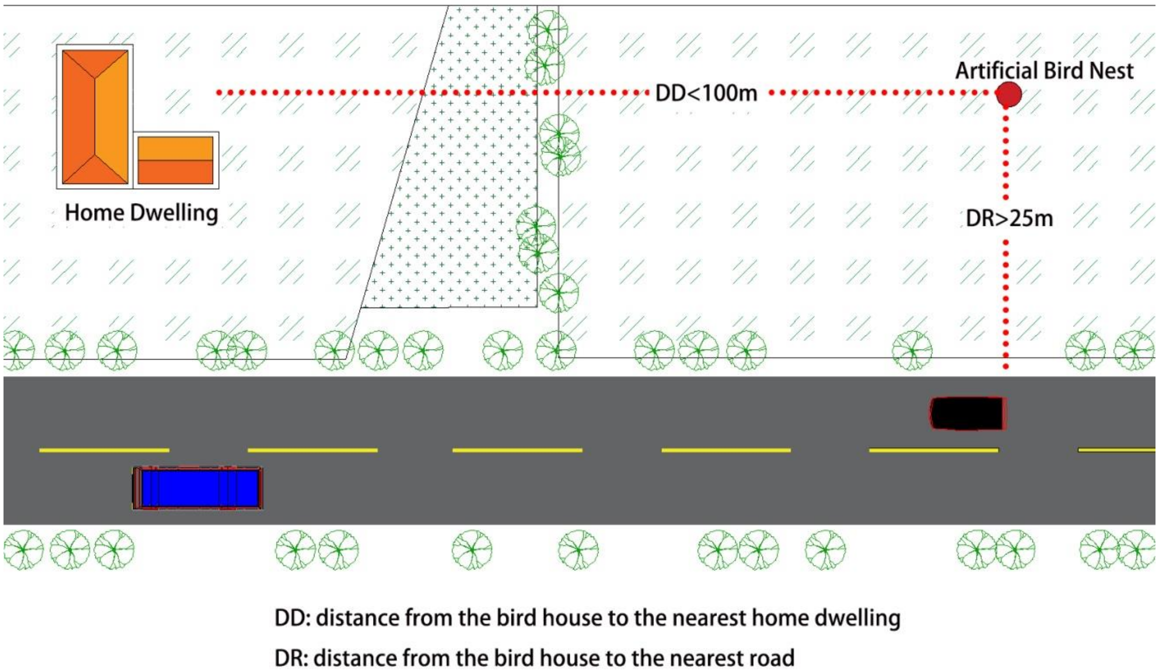

Figure 6.22: Location of an Artificial Nest for *P. domesticus*
Source: Prepared by the author.

(5) Implement flight diverting measures.

Flight diverting measures are commonly implemented for birds with direct and rapid flight pattern, but this measure may also work for *P. domesticus* in some circumstances. For example, when highways run through the farm fields, flight diverters may guide *P. domesticus* to fly above traffic or below the road through bridges. To avoid collisions with the diverters, mark them with flags or paint them with bright colors to stand out in birds' vision.

(6) Plant concealing vegetation along the WVC hotpots on country roads.

Road stretches running through the farmland that produces oat, wheat, millet, sorghum, or corn are *P. domesticus* WVC hotspots. Research has proven that the bird's ground-foraging behavior usually occurs in open, exposed areas (Kociolek *et al*., 2015). Road stretches that are concealed by vegetation cover may be avoided by *P. domesticus* flocks, presumably because of the danger of undetected approach by terrestrial predators (Anderson, 2006). To prevent *P. domesticus* flocks from staying on road stretches that run through farmland, plant numerous trees with big canopies on the roadsides. These trees also serve as diverters to encourage *P. domesticus* flocks to fly over traffic (see Figure 6.23).

Figure 6.23: Plant Concealing Vegetation on WVC Hotpots
Source: Prepared by the author.

(7) Traffic calming

Research has shown that bird WVC may be related to traffic density and speed, season, and weather (Erritzoe *et al*., 2003). Reducing the volume or speed of traffic on a specific road stretch will lessen WVC (Kociolek *et al*., 2015), but investigations of appropriate vehicle speeds are lacking.

- Close road segments that run through *P. domesticus* migration corridors
- Set traffic calming measures such as reduced speed limits and warning signs when salt is used to de-ice roads. There is large quantity of road slat existing after the anti-icing operations in various weather events (snow, freezing rain and sleet). If large flocks of *P. domesticus* have been observed and reported to consuming road salt on a specific road stretch, it is suggested to set traffic calming measures such as reduced speed limit post and warning signs until the salt disappears.

WVC mitigation measures for rural areas mainly involve implementing flight diverters. In urban areas, mitigation measure options are more diverse. The evaluation of the presented plan options are shown in figure 6.24.

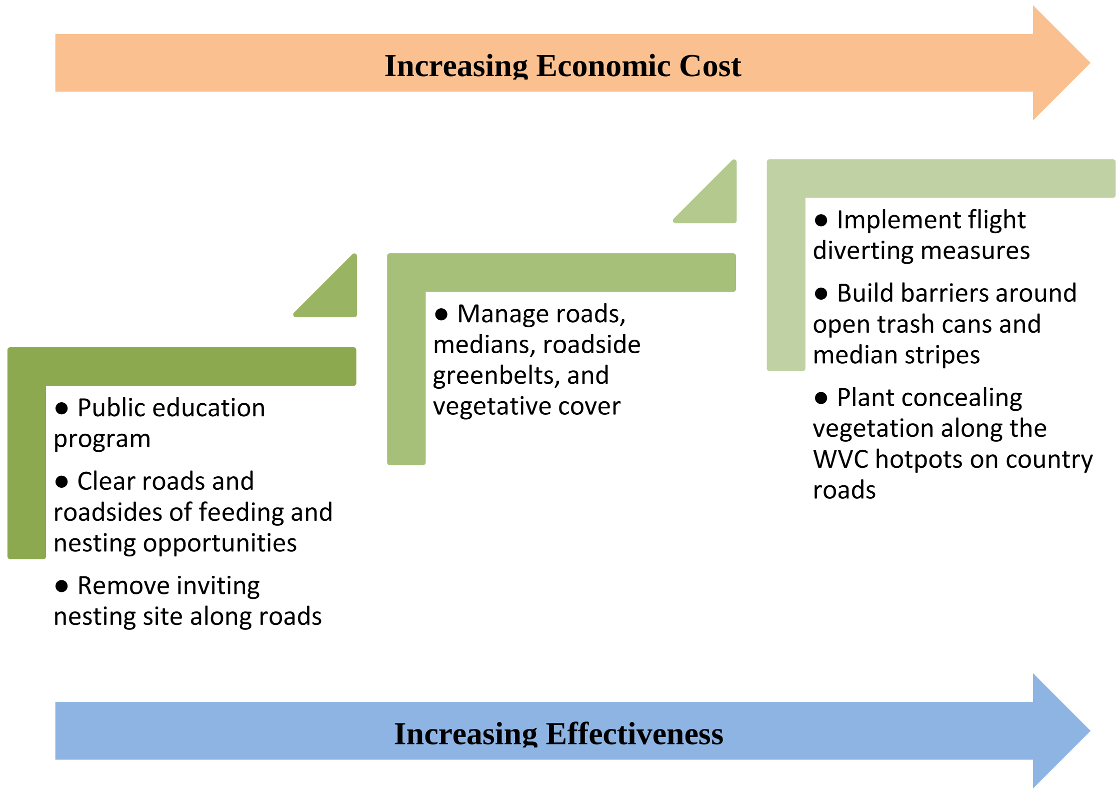

Figure 6.24: Evaluation of The Presented Plan Options
Source: Prepared by the author.

The decision-making process for WVC mitigation in urban areas is shown in Figure 6.25.

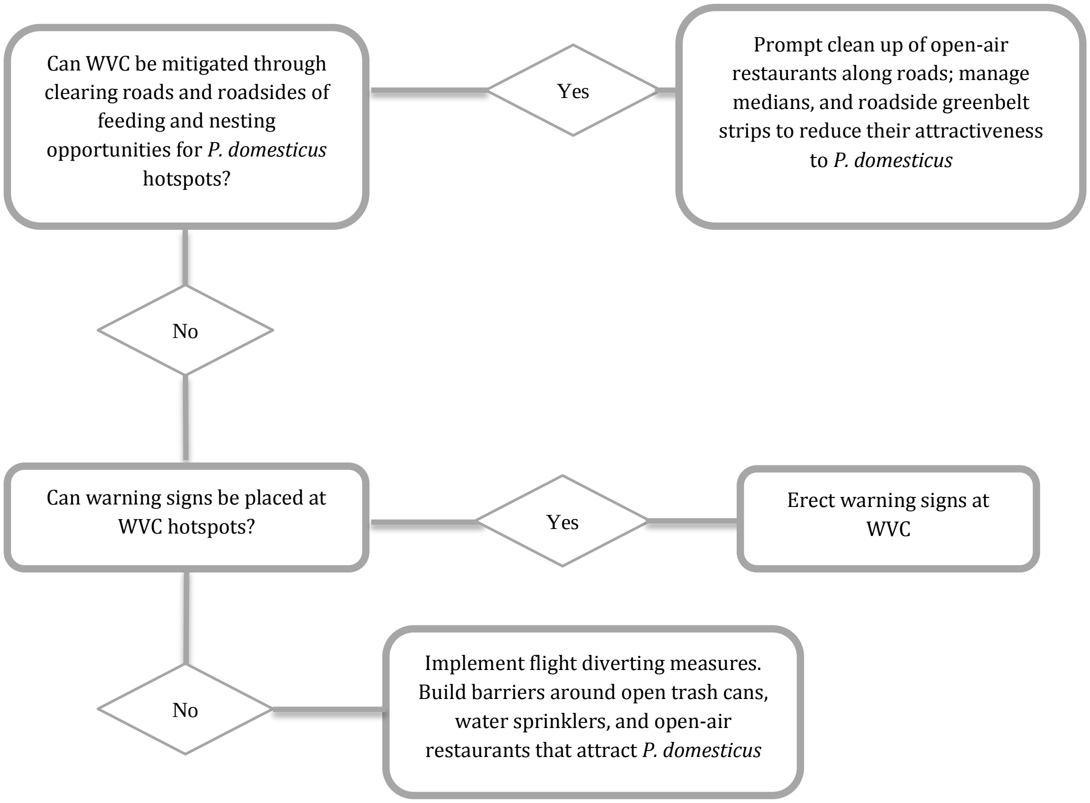

Figure 6.25: Decision-making Process on WVC Mitigation Measures for *P. domesticus*
Source: Prepared by the author.

In the research reviewed for this work, there is little information regarding impacts of WVC on *P. domesticus* populations, or on the effectiveness of existing mitigation measures devised to reduce WVC effects. Without these data, it is difficult to promote an effective WVC mitigation strategy for planners. This section has presented *P. domesticus* WVC mitigation measures on a theoretical level, but further testing is required before they can be recommended as effective approaches.

6.4 Northern Leopard Frog (*Rana pipiens*)

6.4.1 Basic biology

The northern leopard frog (*R. pipiens*) is a slim green or brownish frog. Its normal body length is between 5 and 9 cm, with a maximum of 11 cm (Conant and Collins, 1998). It is a cool climate species; its range encompasses most of the northern United States and into Canada. The species also occurs in the southwestern United States and portions of the Pacific Northwest (Leonard and McAllister, 1996; Smith and Keinath, 2004). The population of *R. pipiens* has declined since the 1960s, with some local extinctions (IUCN, 2016d). It has been put on the provincial Red List in British Columbia and is designated as endangered in southern Canada, but it is still widespread and common in many areas. *R. pipiens* is listed by the IUCN as Least Concern (IUCN, 2016d; Ohanjanian and Paige, 2004; Species at Risk Committee, 2013).

6.4.2 *R. pipiens* and WVC

The suggested causes for *R. pipiens* population decline include habitat destruction, introduction of predators and competitors, pollution from pesticides, acid precipitation, diseases, and climate change. An additional factor is WVC mortality—which is potentially important but has received little attention (Fahrig *et al.*, 1995; Hels and Buchwald, 2001). WVC mortality is a major factor in *R. pipiens* population decline in Indiana, where the species is listed as a species of special conservation concern (Glista *et al*., 2007). Hels and Buchwald (2001) estimated that the probability of amphibians getting killed on a secondary road ranged between 34–61%. The rate increases to 89–98% on main roads; other researchers have made similar conclusions (Mazerolle *et al.*, 2005; Puky *et al*., 2003). *R. pipiens* is listed as an amphibian victim in many field surveys (e.g., Bovbjerg and Bovbjerg, 1964; Carr and Fahrig, 1996; Mazerolle, 2004; Woltz *et al*., 2008). In a four-year survey conducted on a road stretch adjacent to ponds in Ontario, *R. pipiens* accounted for 85.4% of all WVC victims including amphibians, reptiles, birds, and mammals (Ashley and Robinson, 1996); In Eigenbrod *et al.*'s (2008a) survey, a four-lane highway with an average traffic volume of 18,300 vehicles/day acted as a near-complete barrier to *R. pipiens* because of very high WVC mortality rates. The females that are killed in WVCs during breeding season imply a more negative impact on local populations.

As a result of its activity pattern, population structure, and preferred habitats, *R. pipiens* is especially vulnerable to WVC.

- *R. pipiens* needs more than one habitat in its various life stages to meet its needs for foraging, breeding, and overwintering. Breeding migration routes can be as long as 1–2 km. The juxtaposition of different required habitats in the landscape may necessitate seasonal movements. When roads cross its terrestrial habitats, WVC mortality can be substantial (Fahrig *et al.*, 1995; Hels and Buchwald, 2001).
- *R. pipiens* is a vagile amphibian that has strong inherent power of movement. It has large dispersal distances and high dispersal capabilities. More vagile species are more likely to encounter roads especially when

they have no behavioral mechanisms for road avoidance (Carr and Fahrig, 2001).

- Amphibians, including *R. pipiens*, are especially vulnerable to WVCs because they are characteristically slow. In most cases the frog cannot realize the danger of coming vehicles in time to make successful attempts to avoid them (Ashley and Robinson, 1996; Hels and Buchwald, 2001; Lesbarreres and Fahrig, 2012; Woltz *et al.*, 2008).
- The body size of this species is small and, thus, not easily avoided by drivers (Carr and Fahrig, 2001).
- Because of construction considerations, roads are often situated along the edges of geographical features that provide different habitats for *R. pipiens* (Puky, 2003), which increases the possibility of frogs encountering roads.

Some characteristics of *R. pipiens* WVCs include the following:

- Traffic density significantly impacts *R. pipiens* WVC mortality. Road surveys have shown that more frog bodies are found on roads with higher traffic densities (Carr and Fahrig, 2001; Mazerolle *et al*., 2005). Another study concluded that the number of *R. pipiens* victims is greatest on roads with moderate traffic density (approximately 10–18 vehicles/h) (Mazerolle, 2004).
- In the non-migration season, the daily peak in frog activity occurs just after sunset (Hels and Buchwald, 2001).

- WVC mortality is high in late summer and fall due to migration activities (Gibbs *et al*., 2007; Glista *et al*., 2007).
- *R. pipiens* WVC hotspots are associated with wetlands.
- Warm, rainy nights in spring are always used by amphibians to migrate back to breeding ponds, resulting in more WVCs (Jackson, 1996).
- WVC mortality affects more juveniles because they are slower (Hels and Buchwald, 2001). Juvenile dispersal is a major cause of WVC.

The seriousness of WVCs for amphibians has been widely recognized. Preventing or reducing WVC mortality is an essential approach of many conservation activities carried out by NGOs and governmental agencies to resist local population decline (Ohanjanian and Paige, 2004; Stankovic *et al.*, 2015). Current mitigation recommendations include flashing warning signs, temporary traffic bans during migration, or exclusion fences and passages (Barker, 2009). Flashing warning signs in operation during peak migration hours are not effective, due to drivers' poor ability to notice *R. pipiens*' little bodies at night, even with more care than normal. What is more, some drivers deliberately kill frogs with their cars (Puky, 2005). A temporary traffic ban is the most effective measure, however, it is rarely a realistic option. In some locations, volunteer amphibian road-crossing patrols are undertaken to accomplish road crossing during seasonal migration with the help of a temporary exclusion fence. More than 45,000 amphibians are carried over roads every year by volunteers in Slovenia (Langen *et al*., 2009; Stankovic *et al*., 2015).

The most widely used method to reduce amphibian WVCs is the construction of amphibian tunnels. Amphibian crossings have been in use since the first amphibian tunnel was created in 1969, in Switzerland. The United States build its first tunnel near Amherst, Massachusetts in 1989 (Puky et al., 2003). Amphibians may use wildlife overpasses if adequate fencing is provided, but in most cases under-road tunnels with moist environments are preferred (Puky, 2005). Guiding fences and under-road crossings are recommended for locations where WVC mortality is extensive (Ohanjanian and Paige, 2004; Stankovic *et al.*, 2015; Woltz *et al.*, 2008). Although under-road crossings have become a common practice in amphibian WVC mitigation, improvement is needed. There are numerous amphibian crossing infrastructures worldwide that have stopped functioning or never worked properly to begin with. In Hungary, for example, less than half of the amphibian mitigation measures work properly (Puky, 2005). These failures are mainly due to a lack of knowledge among planners, which leads to improperly planned and carried out infrastructures (Stankovic *et al*., 2015).

6.4.3 *R. pipiens* ecology and WVC mitigation suggestions

R. pipiens has low tolerance for human disturbance. Normally it does not forage or live near roads, especially those with high traffic volumes. Seasonal migration and juvenile dispersal are the two main reasons for *R. pipiens* encountering roads. Temporal movement patterns, habitat characteristics, and life cycle have the most significant influences on WVC mitigation strategy development for this species.

Table 6.5 *R. pipiens* Ecology and WVC Mitigation Suggestions

	Behavior	WVC Mitigation Observations and Suggestions
Reaction to Roads	The typical behavior of amphibians when faced with an approaching vehicle is immobility (Mazerolle *et al.*, 2005).	The pause in activity at the approach of a vehicle increases the time that *R. pipiens* spends on roads, thus increasing the chance of mortality. In some cases, however, staying still could be a better strategy than fleeing in a zigzag route (Mazerolle *et al.*, 2005).
	R. pipiens shows no awareness of roads; they are often observed crossing busy roads (Carr and Fahrig, 2001).	Although frogs show low tolerance to roads, they will not avoid roads intentionally during seasonal travel.
	This species often crosses roads in the same location (Puky, 2005).	This fidelity to crossing locations makes it is possible to define *R. pipiens* WVC hotspots.
	R. pipiens population densities decrease along roads (Pope *et al.*, 2000).	Crossing structures should start at points far from road edges.
	Traffic within a radius of 1.5–2 km of a home pond has a significant negative effect on *R. pipiens* abundance (Carr and Fahrig, 2001;	Traffic can influence the population abundance of *R. pipiens* out to at least 1.5 km from the population. This also implies

	Eigenbrod *et al.*, 2008b).	that the majority of *R. pipiens* movements occur within this distance (Carr and Fahrig, 2001).
	Roads act as a complete or almost complete barrier for amphibians. There are findings showing genetic differentiation of amphibian populations separated by major highways (Eigenbrod *et al.*, 2008a).	Mitigation measures are necessary to compensate for the barrier effect of roads.
	R. pipiens move across roads during the night, beginning at dusk. During the peak of migration, they may also move during the day (Puky, 2005).	Warning signs may not work well due to this nocturnal movement pattern. Flashing speed limit signals should be used at peak crossing times to mitigate WVCs.
Seasonable Movement	The species is particularly mobile during summer and fall, and must make long migrations to breeding ponds and hibernation sites (Gibbs *et al.*, 2007).	Seasonal movement is the main cause of road crossing. Summer and fall are peak season for *R. pipiens* WVC occurrences. Temporary mitigation measures or an infrastructure examination should be started before the earliest migration date on record.
	R. pipiens routinely moves up to 8 km during yearly migrations (Eigenbrod *et al.*, 2008b).	The vagility of this species makes it vulnerable to high traffic densities.
	The distance between two habitat locations can be a few meters or up to several kilometers (Ohanjanian	Map all possible habitats for *R. pipiens* to identify WVC hotspots.

	and Paige, 2004).	
	R. pipiens is one of the first amphibians to emerge from hibernation in the spring (Graham, 1997). Spring migration occurs when they abandon their overwintering sites and head to breeding ponds, which is in April in most areas (Ohanjanian and Paige, 2004). Breeding season occurs in spring to early summer.	March to May is the first migration peak of *R. pipiens*. Mitigation infrastructure examination and maintenance should be started as early as February.
	Summer migration occurs in mid-summer. *R. pipiens* travel 1–2 km from major waterbodies to foraging areas (New Hampshire Fish and Game Department, 2015).	Mid-summer is the second migration peak of *R. pipiens.*
	When fall comes, the species moves from foraging sites to overwintering sites. In British Columbia the migration back to overwintering sites may begin as early as August, with the bulk of the movement occurring in September and October[23] (Ohanjanian and Paige, 2004).	Fall migration may occur as early as August. August to November is the third migration peak of *R. pipiens.*

[23] Because *R. pipiens*'s range is restricted to the same climate zone, there is no significant difference in the time of seasonal migrations across its range.

	This species exhibits strong fidelity to breeding and overwintering sites, and great flexibility with respect to foraging areas (Ohanjanian and Paige, 2004).	Defining breeding and overwintering sites is important.
Life Cycle	Breeding occurs from March to June in northern parts of the range, and in any month in southern parts of the range (Conant and Collins, 1998).	Juvenile dispersal may happen over a longer period in the southern part of the species' range.
	Juvenile dispersal can produce even higher peaks in WVC during summer (Puky, 2005).	Foraging activities and juvenile dispersal both contribute to a WVC peak in summer.
	Juveniles typically migrate to feeding sites along larger, more permanent bodies of water, and recently metamorphosed frogs will move up and down drainage basins and across land in an effort to locate new breeding areas (United States Fish and Wildlife Service, 2016).	Juveniles are especially fragile to WVCs due to their slow movement. Roads adjacent to water bodies need special attention.
	Radio-telemetry work suggests that frogs prefer to spend long periods at the edges of water bodies (Ohanjanian and Paige, 2004).	Roads running through wetlands or adjacent to open ponds are potential WVC hotspots.
	R. pipiens need to migrate among different habitats to complete its life cycle (Pope *et al.*, 2000).	A road with contrasting habitat patches on both sides may have a much greater WVC mortality

		potential (Eigenbrod et al., 2008a).
	Generally it prefers to live where there is a permanent body of standing or slow-moving water (Amphibianweb, 2016). *R. pipiens* requires three distinct habitat types: • A breeding pond used in the spring by adults and through mid-summer by tadpoles • Grassy meadows or fields for summer foraging • A slow-moving stream or lake for overwintering (Fahrig *et al.*, 1995; Pope *et al.*, 2000; Smith and Keinath, 2004).	Map these areas as the species' habitat in a GIS system.
	Habitats with short (15–30 cm tall) vegetation appear to be preferred. Tall (>1 m) grass areas are normally avoided (Ohanjanian and Paige, 2004).	Moist grasslands are possible forging sites for the species. Roads running through or adjacent to these areas may possibly produce high WVC rates. These need to be highlighted in a GIS system.
	Overwintering sites include springs, streams, spillways below dams, or deeper lakes and ponds	Hibernation occurs from October to the following March. During this period no mitigation

	(New Hampshire Fish and Game Department, 2015).	measures are needed.
	Although *R. pipiens* normally hibernates in water bodies, it can be found in some terrestrial sites such as crevices (Emery *et al.*, 1972).	In areas where this phenomenon has been recorded by researchers, crevices need to be mapped.
Movement Pattern	The species is primarily nocturnal, but they are frequently encountered by day during summer foraging (Badger, 2005).	The probability of WVC reaches a peak just after sunset (Hels and Buchwald, 2001).
	The species may move as much as 1–2 km between habitats (Pope *et al.*, 2000).	A circle radiating from breeding sites out to 1.5 km can be used to define possible foraging sites.
	Non-seasonal movements can occur at night or during the day. Generally, adult *R. pipiens* do not move very far (i.e., 5–10 m, but occasionally 100 m) before they return to the original location (Ohanjanian and Paige, 2004).	Summer foraging is not a trigger for frequent crossing behavior unless roads run through important foraging habitats.
	R. pipiens is a meadow frog and not good at climbing.	A guiding fence does not to be specially designed to prevent *R. pipiens* from climbing.
Social behavior	*R. pipiens* is a solitary species outside of the breeding season. It does not travel in large groups (Graham, 1997).	*R. pipiens* do not cross roads in large groups. It is easily overlooked by motor vehicle drivers.
	R. pipiens does not establish a	*R. pipiens* may share the same

	home range (Biokids, 2016b). In breeding season, frogs gather at communal ponds in the spring, where males call to attract females.	crossing infrastructure and path.
Others	Many vertebrates prey on *R. pipiens*, particularly garter snakes; pike, pickerel, and bass; and bullfrogs (Gibbs *et al.*, 2007).	Preventing animals from preying on *R. pipiens* at crossing tunnels is important.
	The skin of aquatic amphibians is prone to desiccation, thus, a hydrated environment is preferred (Woltz *et al.*, 2008).	The dehydration rate of the animals' skin is correlated with the substrate type in a crossing tunnel. A tunnel lined with soil or moist grass is preferred to bare concrete (Woltz *et al.*, 2008). A tunnel with its bottom open to the ground is good for maintaining a hydrated environment.
	When frightened on land, *R. pipiens* often seeks water in a series of zigzag jumps (Badger, 2005).	Place the entrance of the tunnel near a water body.
	Woltz and his colleagues (2008) proved experimentally that *R. pipiens* would cross a 9.1 m pipe.	This result is encouraging because road-crossing structures are often longer than 18.3 m.
	R. pipiens prefers tunnels with light penetration, possibly for visibility (Woltz *et al.*, 2008).	Place light reflectors for external sources (e.g., sun, moonlight) at tunnel openings, or install internal light sources (e.g., solar-powered bulbs).

	The species usually gravitates toward heat (Myers, 2016).	A light in the tunnel may act as a heat source to attract *R. pipiens*.
	When migratory conditions change on a given night, *R. pipiens* will either turn back or seek shelter. Frogs caught in the middle of a long tunnel could be killed by freezing temperatures before they find appropriate shelter (Jackson, 1996).	Installing heat sources in long tunnels is recommended.

6.4.4 Suggestions for *R. pipiens* WVC mitigation strategy development

R. pipiens requires various habitats in different life stages. Reduced landscape connectivity between required resources may significantly reduce the capacity of the landscape to support *R. pipiens* populations (Pope *et al*., 2000). Mitigation measures should aim to rebuild and conserve safe corridors that facilitate the species' migrations.

6.4.4.1 Data collection

Create a database of *R. pipiens* distribution and map its main habitats, including core ponds, preferred foraging sites, and known dispersal routes to further define the movement range of *R. pipiens* at the local scale. Road segments running through its movement range are possible WVC hotspots. Information could be gathered from the following sources:

- Research programs. The population decline of *R. pipiens* in many areas has gained attention from local governments and NGOs. Various conservation research programs have been launched (e.g., the state of Washington has conducted an annual field survey since 1999 to monitor the status of *R. pipiens*) (Leonard and McAllister, 1996). The species is included in many research programs on amphibians. The research results provide reliable information on the locations of populations, main breeding ponds, possible foraging sites, overwintering locations, and sometimes even WVC hotspots. Intensive consultation with experts is recommended.
- Field surveys. WVC victim reports are an important source for defining hotspots. However, *R. pipiens* may be difficult to notice due to the deterioration of carcasses by traffic and weather, so a road survey conducted by migration strategy development committee members is recommended. The purpose of a field survey is two-fold. The first is to define locations where *R. pipiens* has been frequently observed. Mark locations of recent sightings of *R. pipiens* through communication with zoologists and others within the species' historic range. A survey is especially necessary when there is no on-going research on local *R. pipiens* populations. The second purpose is to complete a road survey for WVC victims. Road surveys are conducted at potential hotspots, which are selected after reviewing research results and public reports. *R. pipiens*

does not migrate in large groups like some other amphibians, so spatial patterns of WVC cannot be detected with one survey (Langen *et al*., 2009). Multiple road surveys are required. Dead *R. pipiens* are easily missed because they are small and do not last long on roads (Puky *et al.*, 2003). A walking or bicycling road survey in 0.5–1 km segments every morning during migration peaks is recommended.

Though there might be slight alterations according to meteorological conditions, normally crossing sites are spatially and temporally clustered due to *R. pipien*'s fidelity to its habits and migration routes (Puky *et al*., 2003). With the help of color aerial photos, local research programs, and field surveys, a thorough analysis of a landscape with special emphasis on hydrological characteristics should be done in a GIS system. Landscape elements that should be marked in the GIS system include the following:

- Breeding sites. These are warm, open water bodies with 10–65 cm deep water in full sun on the north side of the pond and emergent, non-broad-leaved vegetation for attachment of egg masses. These sites include lake inlets, slow streams, ponds, and temporary wetlands that hold water until at least late summer.
- Foraging sites. Preferred summer foraging sites for the species are land patches with some moisture, typically riparian habitats like wet meadows, pastures, hay fields, scrub vegetation, sedge meadows, or

drainage/irrigation ditches. Areas with short (15–30 cm tall) vegetation appear to be preferred, and tall (>1 m) grass areas are normally avoided.

- Overwintering sites. These are permanent bodies of water or streams that do not freeze to the bottom.

The proximity of natural and artificial bodies increases the probability of WVCs. Causeways, for example, are sites where WVCs are clustered for these taxa. The following kinds of road segments need to be marked as potential WVC hotspots, and further actions need to be implemented at these locations.

- Roads running through wetlands, especially those proven to be *R. pipiens* habitat
- Roads with wetlands or other contrasting habitats on either side of the road
- Roads within 1.5 km of known breeding ponds (see Figure 6.26)

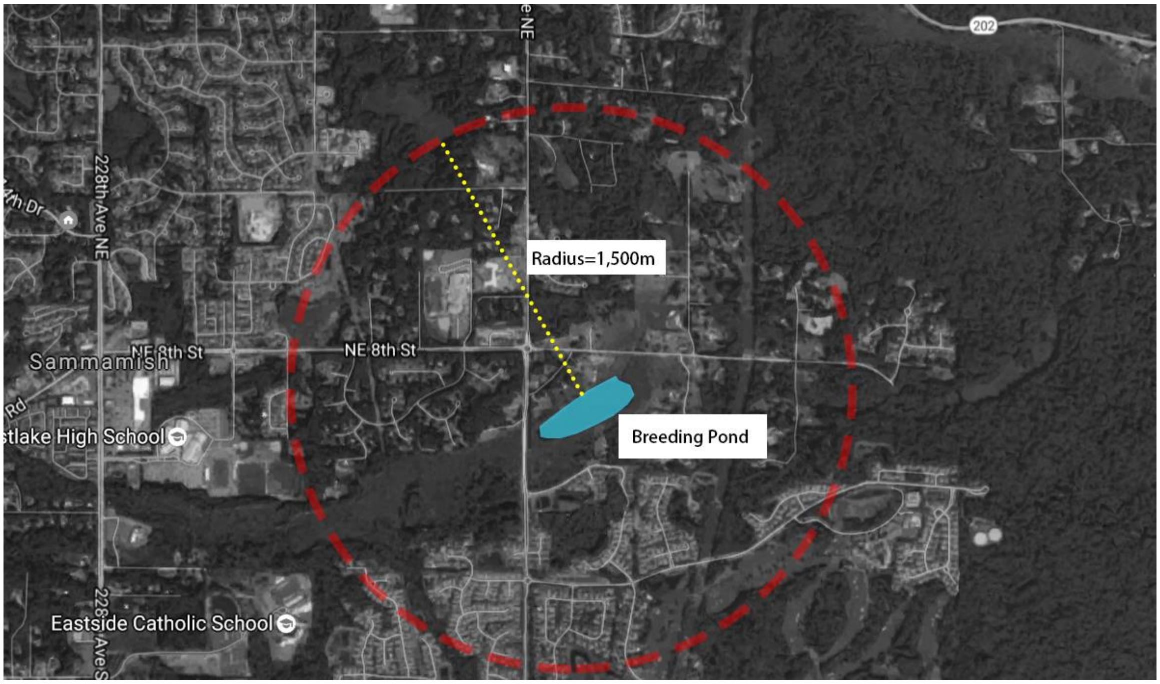

Figure 6.26: Drawing a Home Range for *R. pipiens*
Adapted from photo source: Google Maps

6.4.4.2 Plan action options

(1) Public education programs. Raising public awareness of the following issues may contribute significantly to *R. pipiens* WVC mitigation:

- Peak WVC seasons. From early March to May *R. pipiens* migrates from overwintering sites to breeding ponds. In summer they move to terrestrial habitats to forage. From September to November they migrate back to overwintering sites. WVC peaks are particularly active in summer and fall
- Daily WVC peaks. Daily peaks occur after sunset, especially on the warm rainy nights. In migration seasons *R. pipiens* may cross roads in the daytime.

- Hibernation occurs from October to the following March. There are few *R. pipiens* crossing during this period
- Local *R. pipiens* habitats and WVC hotspots. Make these widely known to the public, and encourage them to proceed with extra caution when they are passing these road segments during migration peak seasons

(2) Traffic calming.

Speed limits. Set speed limits near WVC hotspots to less than 15 mph. As a result of its nocturnal movement patterns, mount speed limit signs along with beacons programmed to flash at night during *R. pipiens* migration seasons (See Figure 6.27).

Figure 6.27: Examples of a Warning Signage and a Speed Limit for *R. pipiens*
Adopted from photo source: https://i.ytimg.com/vi/hVbvKfGZ7xc/maxresdefault.jpg.

Speed limit measures should be combined with improved lighting to improve drivers’ sight. Luminaries might be augmented with overhead lights, or low-level road lights could be installed on both sides (see Figure 6.28). Light intensity must be adjusted so it does not create excessive glare for drivers. At the same time, the wattage should adequate light the road surface.

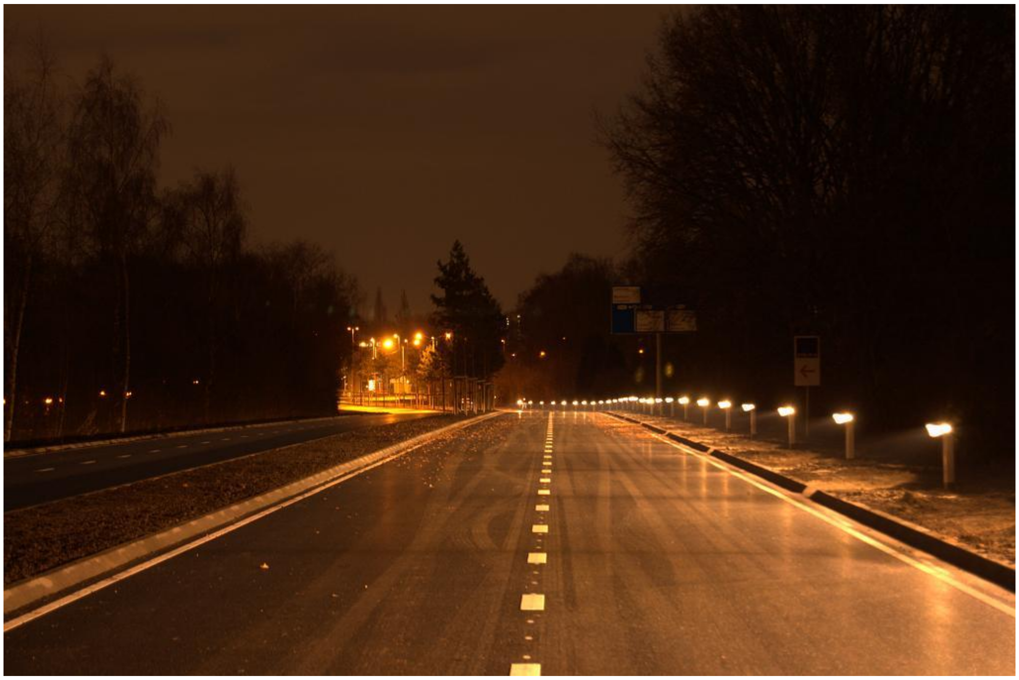

Figure 6.28: Road segment with Low-level Lighting
Photo source: http://www.bermtoerist.org/jalbum/RW63/2008-Week50/slides/20081211-210630.html.

(3) Temporary road closures.

Temporarily close some road segments during migration seasons. Road closure is the best solution to protect road-crossing amphibians. However, there are many drawbacks to this measure. It is only suitable for road segments with low traffic volume, where large migrating *R. pipiens* populations have been observed crossing for more than 2 years and where a detour is easily available. This measure should be implemented when traffic calming is not effective. Road closure should correspond to migration peaks and be as short as possible.

(4) Exclusion fences.

In most cases, exclusion fences should be combined with crossing structures to keep *R. pipiens* off roads and lead them to crossings. Amphibian crossings may not be effective without a fence (Puky *et al.*, 2003; Woltz *et al.*, 2008). Fences should be erected as close to the road as possible, on both sides, with no gaps in them or between fences and crossings (Barker, 2009). There should be a path that is clear from vegetation along the bottom of the fence to allow easy movement of *R. pipiens*.

R. pipiens is not a good climber so the exclusion fence only needs to be 45-60 cm high. Plastic mesh with mesh size of no more than 4 mm or concrete can be used. Polythene fences can be implemented temporarily, but need to be erected in every migration season (Puky *et al.*, 2003). Polythene fences can be installed as an experiment—to investigate the viability of a fence as a mitigation measure—before a permanent fence is installed. Figure 6.29 shows several amphibian fences that made of various materials.

Figure 6.29: Exclusion fences Made of Various Mateirials
Photo Sources: http://www.nicolanaturalists.ca/2014/08/09/if-you-build-it-they-will-come-our-new-toadlet-fence-at-kentucky-alleyne-park-is-working-fine/; https://www.kunststoffrohre-einecke.de/out/pictures/master/product/1/amphibienschutz-------b-l--2-5-10-60-192cm--farbe-grau_4480_0.jpg; http://contractecology.co.uk/amphibian-fencing/; http://www.beilharz.eu/en/amphibian-protection-fence.html.

The bottom 10 cm of the fence is buried into the ground so that frogs cannot crawl under it. The ends of the fence are turned back against road in order to prevent frogs from rounding the fence (Puky et al., 2003) (see Figure 6.30).

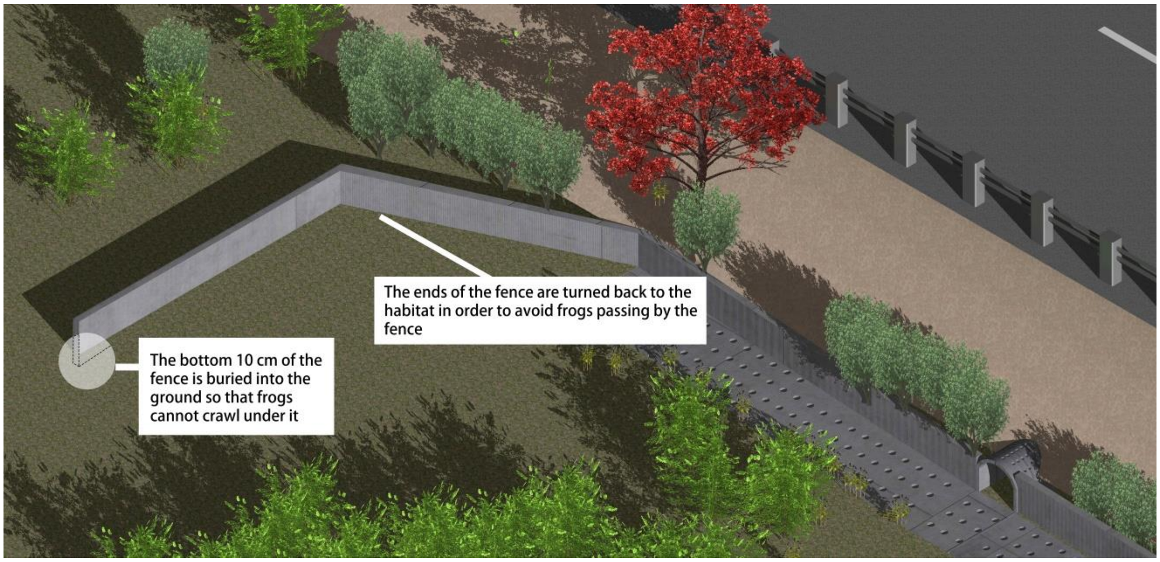

Figure 4.30: Ends of a Fence for *R. pipiens*
Source: Prepared by the author.

Existing fences and tunnels need to be checked before the migration season starts. In the temperate zone of the Northern Hemisphere, the most suitable time for cleaning tunnels is from late February to early March (Puky *et al*., 2003).

(5) Crossings.

Approaches to constructing safe *R. pipiens* crossings are as follows:

(a) Existing passages

The presence of culverts, drain pipes, viaducts, bridges, game passages, or other potential crossing infrastructures reduce amphibian WVC mortality (Langen *et al*., 2009). Retrofitting existing crossing infrastructure to improve use by *R. pipiens* is an effective and economic mitigation measure (see Figure 6.31).

- Design a dry ledge in existing culverts if there are no banks on either side

Open-span crossings over a natural stream with wide banks on both sides work for most species, including amphibians (Lesbarreres and Fahrig, 2012). For those without banks, the most common way to retrofit an existing culvert is to design a dry ledge. The design needs to balance minimal special requirements and hydraulic constrains. Trocme and Righetti (2011) presented requirements for amphibian culvert retrofitting: the minimum width of a dry ledge is 0.4 m, and the minimum clearance over a dry ledge is 0.6 m.

Figure 6.31: Two Examples of Existing Culverts
On the left the culvert is missing a dry ledge so it cannot be used as a crossing by R. pipiens. On the right there are wide banks on both sides of the culvert and it needs no further modification. Taken from: Trocme et al., 2011.

- Design artificial water bodies on overpasses or on either side of them

Overpasses designed as mitigation measures for larger animals such as mammals can also be used by *R. pipiens*. To improve use, small water bodies could be designed on each side, which would probably improve the stepping stone function of the bridge, as a viaduct for crossing amphibians (Puky, 2003). Vegetation cover on the overpasses also can help keep it moist.

- New culverts. Requirements for dry ledge dimensions in new construction are slightly larger than for retrofitted ledges. The minimum width is 1 m, and the minimum clearance over the edge is 0.75 m (see Figure 6.32) (Trocme and Righetti, 2011).

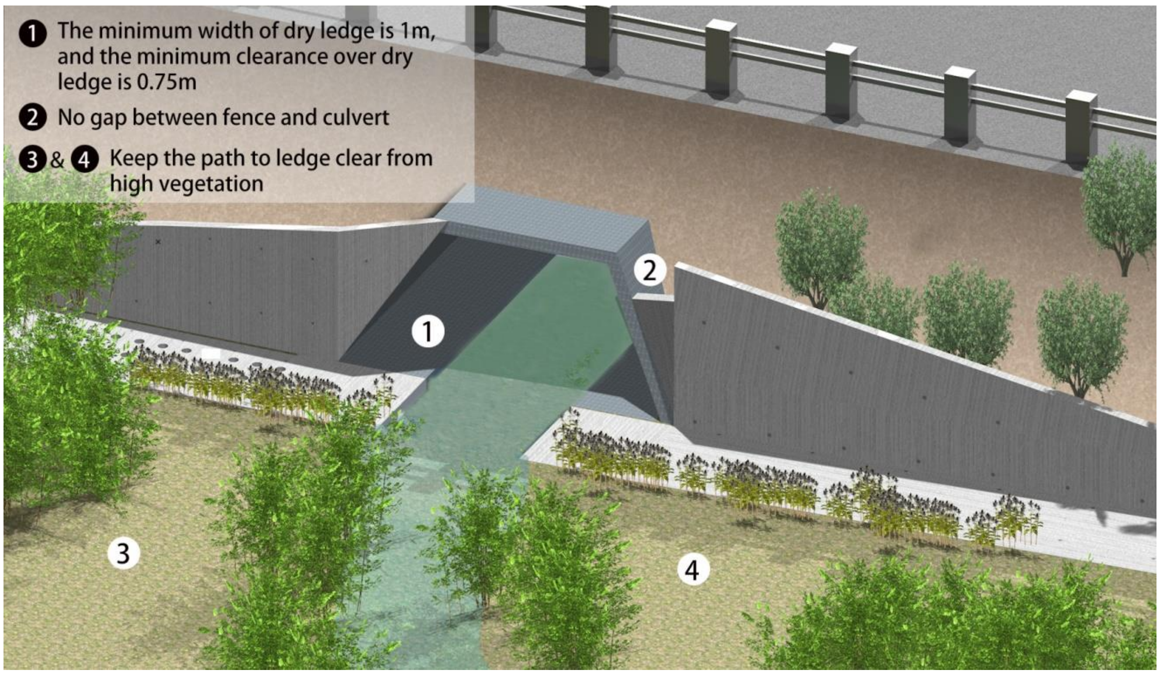

Figure 6.32: Culvert Retrofitting with Dry Ledge
Source: Prepared by the author.

(b) Under-ground tunnels

Underground tunnels are effective for WVC mitigation on two-lane roads. It is unclear whether this technique will be as successful with large highways (Barker, 2009). Tunnels should be considered as a mitigation measure when the road segment is proven to be a WVC hotspot.

Current tunnels used in amphibian WVC mitigation are diverse in material and shape. Some are constructed out of round PVC pipe. For economic considerations, concrete and polymer concrete are the most widely used construction materials (Puky *et al*., 2003). With the help of technology, some amphibian-friendly materials (e.g., ACO climate tunnels) that could allow rainfall and moisture to penetrate better are on the market. These materials offer a better option.

As to the shape of the tunnel, both rectangular and circular tunnels are appropriate. The bottom should be lined with soil, water, or grass to create a hydrated environment, as well as make a relatively flat surface to facilitate use. The ideal shape of the tunnel is a horseshoe with the bottom open to allow moisture from the ground inside the tunnel.

There is no consensus on ideal tunnel dimensions. Puky *et al*. (2003) have stated that larger tunnels are more frequently used by amphibians than smaller ones. The minimum diameter of tunnels is recommended to be 100 cm. When the tunnel is longer than 20 m, the minimum size of the tunnel may be larger, up to 200 cm by 150 cm or 200 cm in diameter. Tunnels larger than 500 cm in diameter can maximize the amount of ambient light inside the tunnels (Jackson, 1996; Puky *et al*., 2003; Woltz *et al*, 2008).

The following measures can be used to improve the use of fence-tunnel systems:

- A path network should be used to guide frogs to the tunnel entrance, starting from its habitat. Ecological elements such as water bodies and grass are recommended for constructing the network (see Figure 6.33).

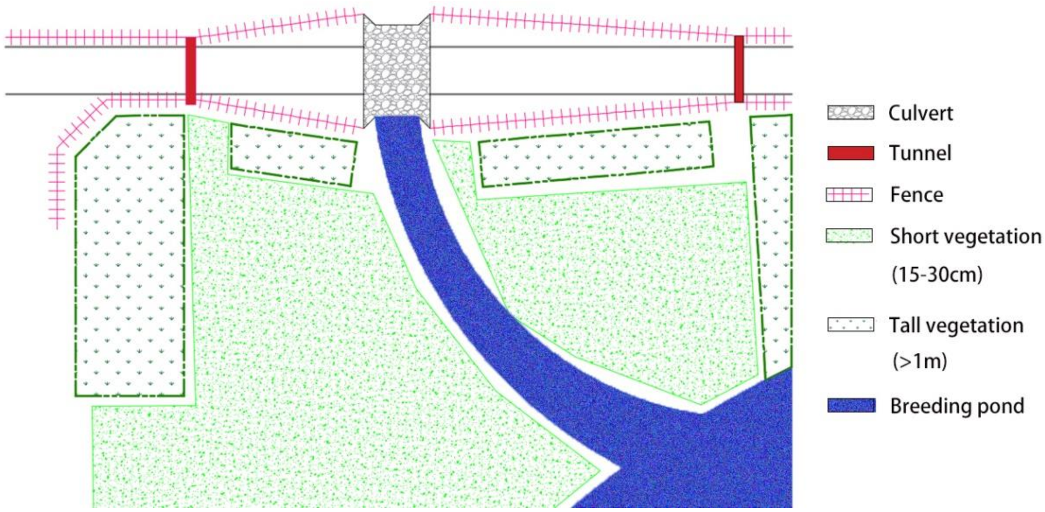

Figure 6.33: Path Network to Funnel *R. pipien's* Movement
Source: Prepared by the author.

- *R. pipiens* shows tunnel hesitation when light conditions are not good inside. Adequate light in the tunnel can improve use (Puky *et al*., 2003; Woltz *et al*., 2008). Tunnel segments could be equipped with slotted tops to allow rain and light to enter (Jackson, 1996). Light reflectors for external sources (e.g., sun, moonlight) at the tunnel openings, or internal light sources (e.g., solar-powered bulbs, light shafts, holes) can be installed in the tunnel. Internal lights can also serve as sources of heat (see Figure 6.34).

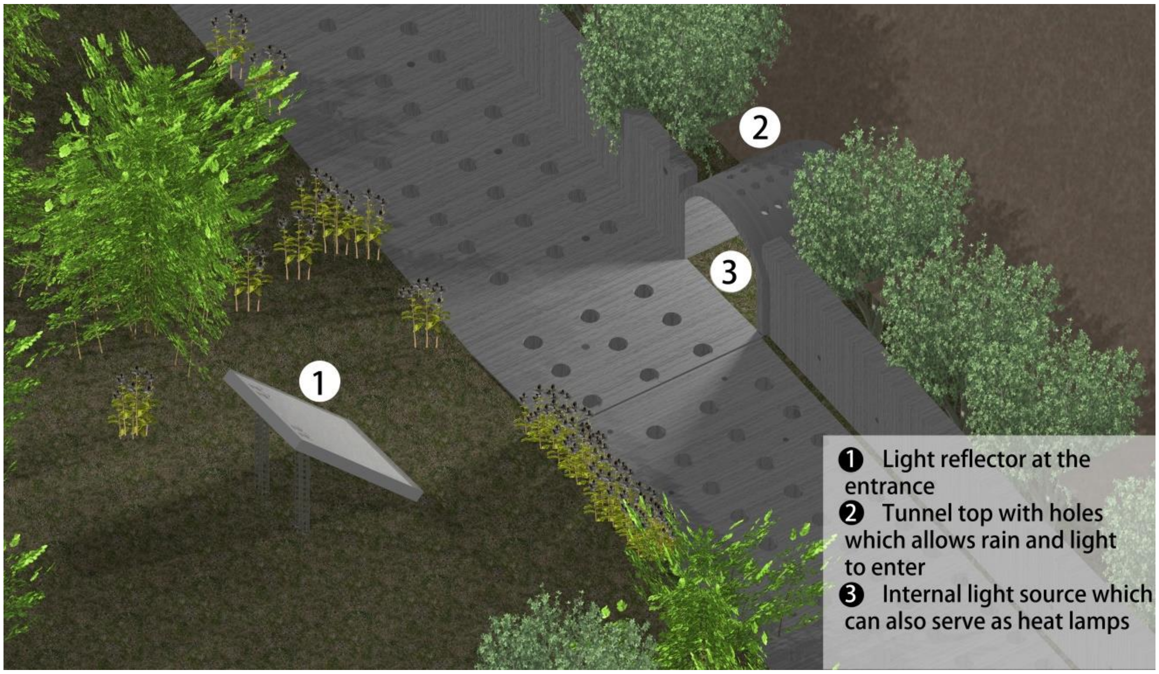

Figure 6.34: Lighting System for *R. pipiens* Tunnel
Source: Prepared by the author.

- Considering the long migration distance of the species, the maximum distance between tunnels is suggested to be 80–100 m (Puky *et al*., 2003). Tunnels can be more numerous throughout road networks in ecologically sensitive area.
- Keep the tunnel entrance lower than or flush with ground level to make it easily accessible. The accessibility of the entrance is a key design issue in keeping tunnels functional. If the entrance is above the ground, i.e., the frogs need to jump or climb to reach it, they may move farther along the fence without entering the tunnel (Puky *et al.*, 2003). Regular maintenance is necessary to prevent blocked entrances.

- Set tunnel entrances close to existing water bodies to improve use.
- *R. pipiens* requires wet conditions for their migrations. Tunnels should be neither completely waterlogged nor completely dry (Barker, 2009), and built slightly above the water table, around 300 mm. Tunnels with their bottom open to the ground or with drainage holes on the floors are recommended. In periods of drought, the system benefits from direct connect to the ground moist. Figure 6.35 is a 3D view of the tunnel-fence system.

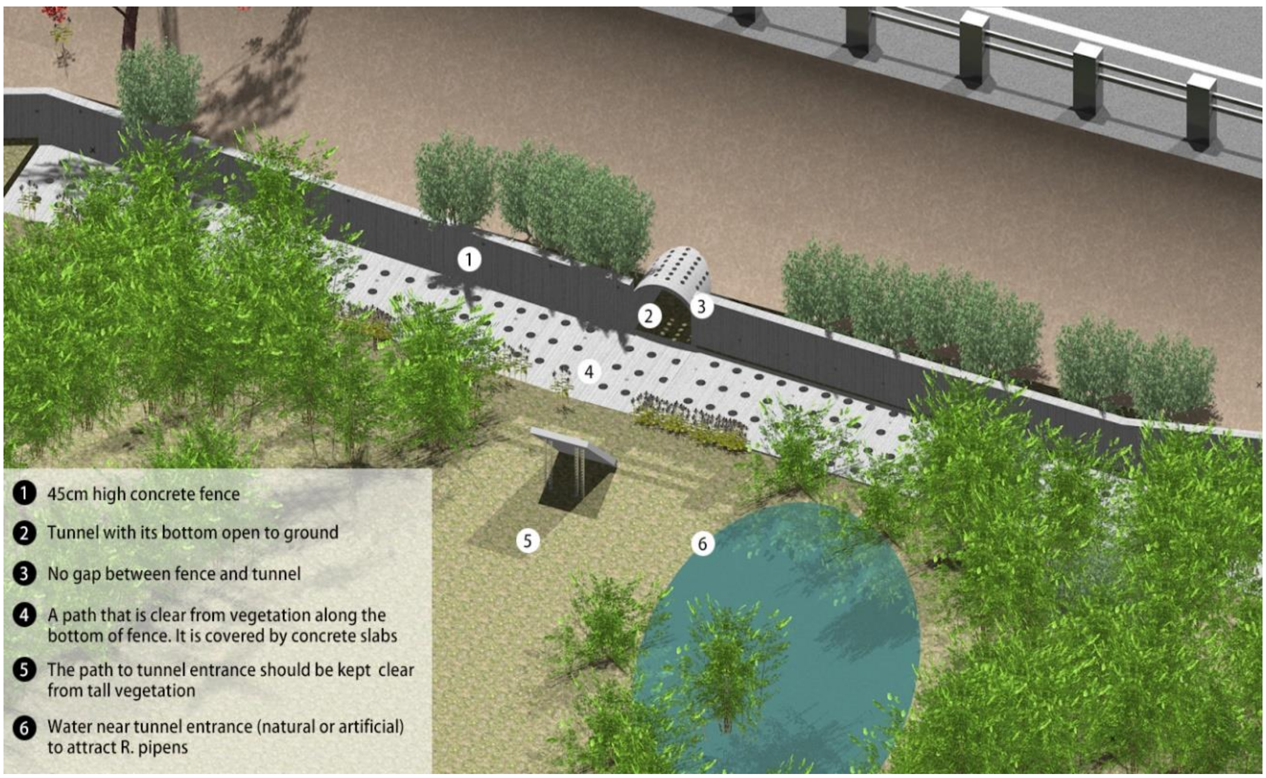

Figure 6.35: 3D view *of R. pipiens* Tunnel and Fence
Source: Prepared by the author.

The evaluation of the presented plan options are shown in figure 6.36.

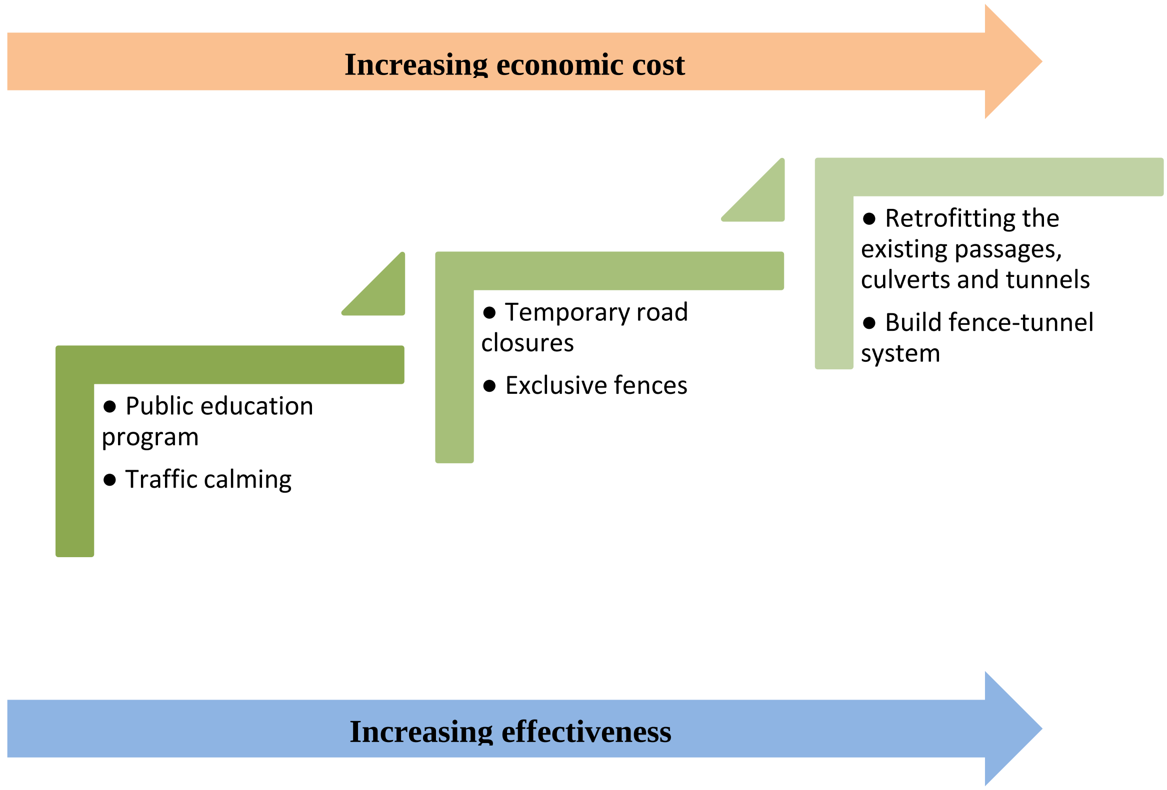

Figure 6.36: Evaluation of the Presented Plan Options
Source: Prepared by the author.

The decision-making process for WVC mitigation is shown in Figure 6.37.

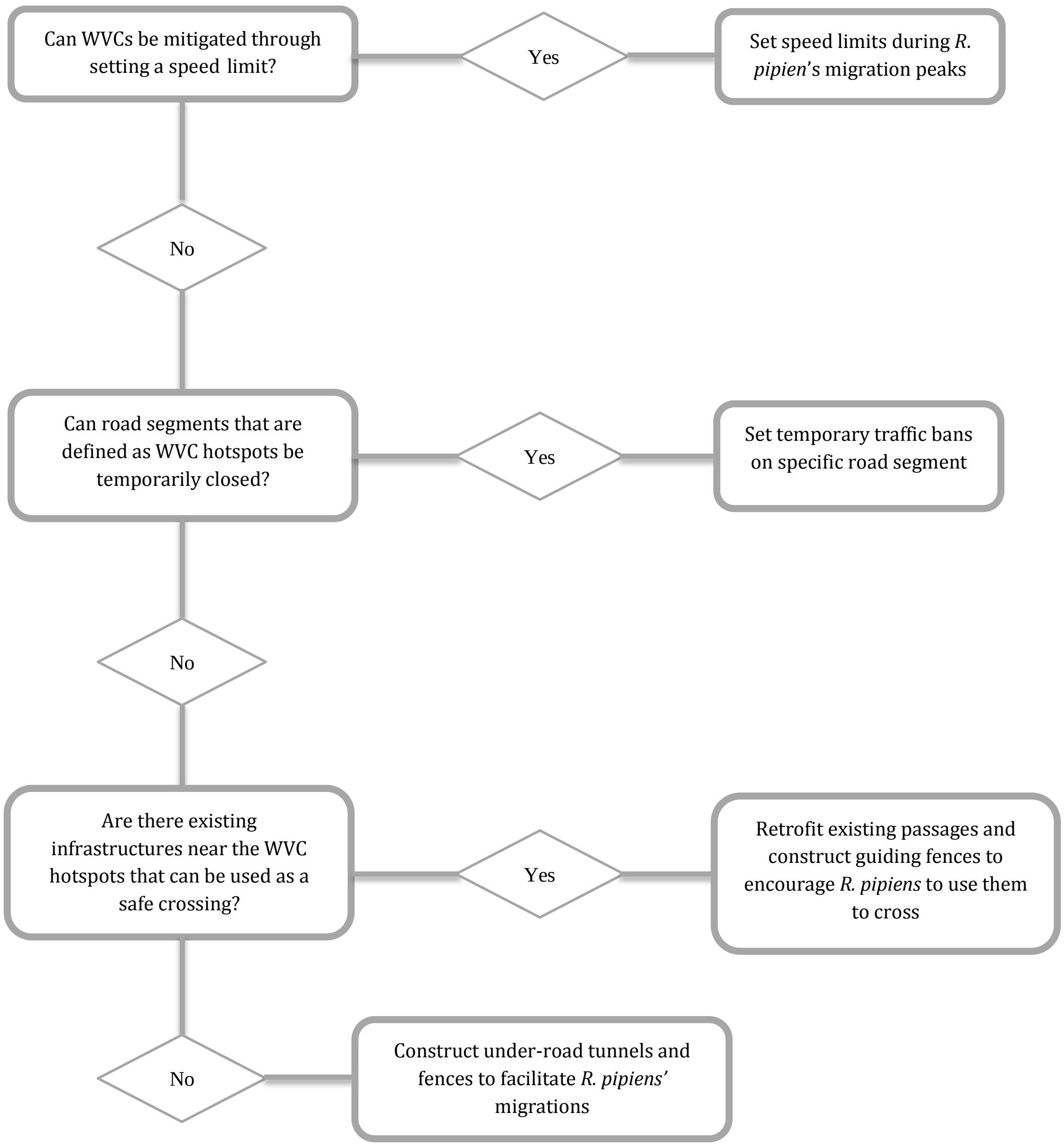

Figure 6.37: Decision-making Process on WVC Mitigation Measures for *R. pipiens*
Source: Prepared by the author.

Chapter 7

CONCLUSION

7.1 Introduction

> *How do our current ecological science results apply to the diverse types of roads and traffic levels criss-crossing the land? The ecology of road segments and especially road networks in a landscape cries out for study…. What is the optimum distance between road-crossing structures for different wildlife types? How can the ubiquitous utility poles along roads be used in mitigation solutions? To understand roads and wildlife populations, the non-roadkill dimensions now need much greater emphasis…. This dimensions are lurking giants, awaiting a few prescient researchers and leaders.*
>
> Richard T.T. Forman (2015, Forward, p. 11)

Road networks play a significant role in shaping the ecological environment. Many roads were built before the rise and spread of ecological preservation through society. Some Ill-considered road projects act as barriers to fauna movement. WVCs occur when animals attempt to cross roads to reach different habitat patches. Many animals in human-dominated landscapes are exposed to a high risk of WVC. However, despite high occurrence rates, WVC mitigation measures have not been implemented widely. There seems to be a consensus of opinion that in most cases WVCs do not demand immediate action because they do not impose significant impacts on the total populations of species, and a species often found killed on roads may simply reflect the presence of large thriving populations. There is a long-standing method to identify the alarm threshold for WVCs—the proportion rather than the total number of a population killed in WVCs is used as an indicator. WVCs that involve medium- and small-size animals get even less attention because they do not lead to high economic and human health costs. This opinion discourages efforts toward WVC mitigation.

Various ideologies or movements that have emerged to reinforce the importance of wildlife preservation have not reached the root of the problem. Illuminated by *deep ecology*, this dissertation offers a new perspective to examine WVCs—all life forms should be examined in terms of what is ethically right instead of what is socio-economically manageable. Beyond a set of theoretical propositions and ideas, a political ecology approach can refer to the values guiding an environmental movement (Atkinson, 1991). In the framework of political ecology, deep ecology calls for a change in both ideology and methodology to respond to the wildlife loss in WVC. The motivation to develop a WVC mitigation strategy is first to preserve life and reduce suffering rather than maintain the local ecosystem or reduce economic losses.

This dissertation explores WVC mitigation from the perspective of urban planning. The premise of this research is that planning departments could and should play leading roles in mitigating WVCs. Every stage of WVC mitigation—planning, designing, constructing, and maintaining—requires interdisciplinary collaboration. Planners can be especially creative in combining procedural and substantive skills from once-separated disciplines and, thus, become leaders in the battle against WVCs. In addition, only the planning department through its regulatory powers, has the ability to enact standard rules to ensure that the benefits of non-human life will not be ignored.

Urban planning has a long tradition to serve human being. This research flows from this strand of urban policy research, and examines value-based biases in the current paradigm of urban planning research. Through introducing deep ecology to urban planning, this dissertation suggests that urban planning research should spur a paradigm shift from anthropocentrism to eco-centrism. The new paradigm calls for planners to be more respectful of the intrinsic value of life, and to pay more attention to non-human species. The motivation to mitigate WVCs should be not only to ensure human safety but also to save animal lives. It is necessary to understand that humans and wildlife share a common need to move. Wildlife issues should be considered during every stage of road planning to improve the ecological outcome of a road.

Under the new paradigm, this dissertation develops a WVC mitigation framework. The framework integrates environmental science and policy by using ecological information to develop effective local WVC mitigation measures. The ecological information includes knowledge about the following: a) Species' crossing behaviors. Knowledge of whether animals would avoid roads, how they choose crossing locations, frequency of crossings, behavioral mechanisms in response to approaching vehicles, and numbers of documented WVCs forms the premise for the deployment of mitigation measures. b) Typical species behavior and habitat characteristics. These information sources predict animals' reactions around roads and help us to choose appropriate mitigation measures. Only with respect for life and profound ecological understandings will we be able to design sufficient and effective mitigation measures to fight WVCs on existing roads.

7.2 Findings and Contributions

7.2.1 A complementary paradigm—deep ecology

The root of most human–wildlife conflict lies in a dominant value system—anthropocentrism. Traditionally, urban planning is a field that separates humans from nature and promotes the development of cities at the cost of natural environment destruction. A road is built to improve human mobility, while hardly considering the welfare of other life forms. Under this paradigm, wildlife is attributed little value, particularly when set against economic benefits. As a result of exclusion of wildlife from the whole picture, urban planning is open to human–wildlife conflict.

The economic valuation, which is derived from the anthropocentric ideology, demands that the advantages and disadvantages of a WVC mitigation strategy be reduced to numbers, and then further reduced to dollars and cents (Ackerman and Heinzerling, 2002). The value of life never has been subjected to rigorous economic valuation. This feature of economic valuation makes it terrible way to make decisions about WVC mitigation, for both intrinsic and practical values. With this evaluation approach, the key determinants of successful WVC implementation are whether the WVC mitigation projects are cost effective and whether society can save money through reductions in the rates of human death, injury, and property repair. In this case, wildlife that is negatively affected by WVCs will not get enough attention and protection unless serious economic or human life losses occur.

Lynch (1984) stated that: "Once we can accept that the city is as natural as the farm and as susceptible of conservation and improvement, we work free of those false dichotomies of city and country, artificial and natural, man versus other living things" (p. 257). The objective of urban planning is not to separate cities from nature, but to minimize the threat that a city poses to nature. To deal with human–wildlife conflicts in urban areas, we must take a step in the direction of deep ecology, which attributes moral significance to nonhuman beings. This ideology advocates biocentric equality and stresses the connections among species, including humans, and to the environmental conditions that support all life on earth. Nature is treated as a formidable preexisting condition that cannot be easily altered, and wisdom in the stability of natural processes should be respected. Anthropocentrism is thus discredited in the framework of deep ecology, because animals should be given the same consideration as humans, within the sphere of morality. To impose a low impact on wildlife should be one of the priorities of any urban planning and construction project.

Deep ecology can become a powerful motivation to spur a paradigm shift in urban planning from anthropocentrism to ecocentrism. The new paradigm will help planning research move directly away from anthropocentrism. Planning deals with multiple objectives. In practice, planners confront deep-seated conflicts among economic, social, and environmental interests. They cannot act as an environmentalist because they face constant professional and fiscal constraints. It is reasonable for planners to give serious consideration to the utilitarian principle, and in many situations planners will create a development scheme that harms some interests—in most cases, wildlife interests are sacrificed. An ecocentric paradigm, which is illuminated by deep ecology, is not a description of an alleged actual equality between human and wildlife, it is a prescription for how we should treat other beings. It is hardly possible to realize a radical egalitarianism in our life, but the planning community is encouraged to move the discipline toward wildlife-friendly practices in an evolutionary progression. At a practical level, deep ecology sets an objective for development: during the process of social construction of nature, planners are required to try their best to avoid the materialistic pitfall of arrogantly denying any aspects of nature beyond the labor theory of value. Only with respect for all living beings, like humans, animals, plants, and even microbes, will a solution to human-wildlife conflict be identified.

From a political point of view there is certain need for priority setting due to the time and money consuming way of environmental valuation (Brauer, 2003). This approach is incomplete in valuating either the loss in WVC, or the benefits in developing WVC mitigation strategies. The ecocentric paradigm contributes to WVC mitigation strategy development in twofold: first, it acts as a strong motivation to mitigate WVCs. Wildlife is protected for its own sake. Urban planners are obligated to protect victim species, and they are willing to adopt innovative regulatory policies and programs to avoid WVCs. WVC mitigation is not seen as an expensive burden, but a necessary way to protect the welfare of animals and to end cruelty to them. In the process of decision making, this new paradigm gives planners more political support. The new paradigm is essential to ensure a WVC mitigation strategy is implemented to the highest standard and to engender a process of innovation for future projects. Deep ecology principles can be used to change assessments of mitigation strategies by relying on ecocentric evaluation tools such as zero discount rates. Ecocentricism should act as a complementary paradigm to economic valuation.

Second, an ecocentric paradigm ensures that ecological considerations are involved in planning. The WVC mitigation plan should set animals as the clients of urban planning and the users of WVC-mitigation infrastructure design. According to the principles of user-centered design, study of a species' basic biology and its behavioral characteristics is an important stepping stone in seeking solutions to WVCs.

7.2.2 A mitigation framework

Economic valuation is not reliable in developing effective WVC mitigation strategy. Deep ecology, as a non-quantitative approach, is used to complement the traditional cost-benefit analysis. This ideology emphasizes that wildlife is valueless, and the most effective WVC mitigation measure should be taken to avoid any wildlife loss in WVC. WVCs can be understood only by combining the perspectives of planning and ecology. This dissertation designed a WVC mitigation framework which puts the effectiveness rather than economic efficiency as its top priority. This framework works out details of mitigation strategy and narrows the gap between theory and practice. It can be used by government agencies, planners, and designers to develop mitigation strategies for local affected species.

This framework has two distinguishing characteristics that are not represented by prior strategies. First, it emphasizes the leading role of the urban planning agency in WVC mitigation strategy development. Governmental intervention is necessary in mitigating WVC. A planning agency's work should span the project continuum—from planning and design, through construction, and into maintenance and management. As a steering community, planning agencies need helps from the following three areas: 1) the science community, which is comprised of scientists in ecology, transportation, and architectural design; 2) the partnership community, which is comprised of transportation agencies, NGOs, and volunteers; and 3) local experts and the public.

Second, it stresses the importance of ecological information in developing an effective mitigation strategy. The ecological information that may contribute to WVC mitigation includes:

- the target species' WVC patterns
- Habitat characteristics

- Species-typical behavioral characteristics
- Life cycle

The research develops a general framework showing how to apply biological knowledge of species-typical behaviors and habitat characteristics to develop species-specific mitigation measures. This framework is designed under a new, ecocentric paradigm. It has the following characteristics, which are distinctive from previous framework characteristics:

- It guarantees that WVC mitigation efforts receive more attention and resources.
- It guarantees that all victim species can get attention.
- It lowers the threshold for initiating a WVC mitigation strategy.
- It guarantees more effective WVC mitigation measures will be explored.

The framework is developed in an ideal scenario, without being restricted by social or economic limits. Ideally the mitigation strategy should be species specific to maximize its effectiveness, however, in practice financial considerations would dictate that most mitigation strategies be developed to address more than one species.

7.2.3 Species-specific mitigation strategies for four species—European badger, eastern gray squirrel, house sparrow, and northern leopard frog.

As an application of the framework, this dissertation develops detailed species-specific mitigation strategies for four frequent WVC victim species—European badger, eastern gray squirrel, house sparrow, and northern leopard frog.

The strategies contain detailed information on preparation, development, and implementation.

All the four species are frequent WVC victims, but due to their small body sizes, as well as their population abundance, they have received little attention for WVC mitigation. They are still crossing roads without any protection. Under an ecocentric paradigm, the total number of individual losses of a species in WVC is a determinant in initiating a WVC mitigation plan. So through research on their ecological and biological characteristics, this dissertation develops detailed WVC mitigation plans for the four species.

WVC Mitigation strategy for European badger (*Meles meles*)

- Public awareness and education programs.
- Remove grass verges along roadsides within 50 m of hotspots.
- If WVCs do not decrease to an acceptable level, erect a warning signage on WVC hotspots.
- If WVCs do not decrease to an acceptable level , takespeed-reducing measures such as speed bumps and raised level-crossings, either temporarily or permanently, to reduce vehicle speeds as well as volumes. A low speed limit, from 15–25 mph, is suggested.
- If WVCs do not decrease to an acceptable level, erect *M. meles* reflectors at WVC hotspots to deter the animals from crossing at night.

- If WVCs do not decrease to an acceptable level, construct a network of *M. meles* setts, paths, crossings, and fences to funnel the animals to cross roads at a safe crossing.

WVC Mitigation strategy for eastern gray squirrel (*Sciurus carolinensis*)

- Public awareness and education programs.
- Clear roadsides and design median strips to make them less attractive to this species.
- If WVCs do not decrease to an acceptable level, erect warning signage and set speed limits near WVC hotspots.
- If WVCs do not decrease to an acceptable level, clear road verges of vegetation to more than 10 m.
- If WVCs do not decrease to an acceptable level, implement aerial bridge web around WVC hotspots to facilitate crossing. An exclusion fence or vegetation clearance is recommended in association with the bridge web.

WVC Mitigation framework for house sparrow (*Passer domesticus*)

- Public awareness and education programs.
- Prompt cleanup of open-air restaurants along roads; manage roads, medians roadside greenbelt strips, and vegetative cover to reduce their attractiveness to *P. domesticus*.
- If WVCs do not decrease to an acceptable level, remove inviting nesting sites, such as cavities and vents on the outer walls of buildings, hollow

cross poles for traffic lights, and so on along roads to reduce the possibility of fledglings encountering vehicles.

- If WVCs do not decrease to an acceptable level, erect warning signs or speed limits near WVC hotspots.
- If WVCs do not decrease to an acceptable level, implement flight diversion measures.
- For country roads that run through farmlands, plant concealing vegetation along WVC hotpots.

WVC Mitigation Strategy for northern leopard frog (*Rana pipiens*)

- Public awareness and education programs.
- Set speed limits during *R. pipiens*' migration peaks. The speed limit near WVC hotspots should be less than 15 mph. Speed limit measures should be combined with improved lighting to improve drivers' sight.
- If WVCs do not decrease to an acceptable level, set temporary traffic bans on specific road segments during migration seasons.
- If WVCs do not decrease to an acceptable level, retrofit existing passages and construct guide fences to encourage *R. pipiens* to use them to cross. Existing culverts, drain pipes, viaducts, bridges, and game passages all can be potential crossings for the species.
- If WVCs do not decrease to an acceptable level, construct under-road tunnels and fences to facilitate *R. pipiens*' migrations. A path network

should be used to guide frogs to the tunnel entrance, starting from their habitat. Ecological elements such as water bodies and grass are recommended for constructing the network.

The mitigation measures presented in this chapter are unproven, and further research is required before widespread implementation. The design and planning of mitigation measures, for example, crossing structures, fences, and wildlife detection systems, should evolve as our understanding and technology improves (van der Ree, 2015).

7.3 Final Thoughts

7.3.1 The importance of evaluating the ecological impact of a road in the preconstruction stage

Appropriate ecological input into a road project should occur at all stages (Roberts and Sjolund, 2015). The WVC mitigation strategy addressed in this dissertation involves mainly post-construction mitigation measures that are implemented on existing roads, especially those that were built without solid ecological considerations. Nevertheless, it is vital to include ecological considerations in the preconstruction stage of road building. The profound ecological impact generated by roads begins during the early stages of construction and progresses through completion and daily use (Andrews *et al*., 2008). Preconstruction planning is generally more economical and efficient than retrofitting existing roads. Ecological outcomes, including WVCs, of a given road should be included during environmental impact assessments (Gilster *et al.*, 2009; Roberts and Sjolund, 2015). Once an ecosystem's structure and function are disturbed, they are not easy to restore.

Road development is often used as an indicator of socioeconomic development (Selvia *et al*., 2015). It is a cost-effective way to promote regional integration and spur economic growth. The expansion of road networks is driven by the needs of developing nations to improve transportation and energy infrastructures. A preconstruction evaluation is especially important in developing countries where road networks are rapidly expanding. The rate of major road construction in developed countries, such as in the United States, Australia, and Western Europe has slowed, while it is rapidly increasing in developing countries, such as those of Asia, South America, and Africa (van der Ree, 2015). Obsessed by pursuing an economic boom, planning agencies in the developing countries typically neglect ecological considerations in road construction.

Roads, especially those that penetrate relatively pristine regions, are seen in a negative light because they open a Pandora's box of environmental problems. "Habitat fragmentation equals extinction" (Tallamy, 2007, p. 31). Roadless areas are precious resources in the preservation of biology. As a result of the low level of human disturbance, wide arrays of ecological processes are preserved. Roadless areas are crucial for keeping communities of life untrammeled by humans, and are especially important for species that move across large habitats, such as brown bears, wolves, or elephants (Selva *et al.*, 2015). The first road in any roadless area[24] is ecologically dangerous, because it opens the land up for more roads and development, and triggers significant land-use changes, resource extraction, and human disturbance. Keeping roads out of surviving irreplaceable natural areas is among the most tractable and cost-effective ways to protect crucial ecosystems (Laurence, 2015).

In the pre-construction stage, adjusting the spatial distribution of future land use is a potential solution to control road network sprawl and conserve untapped nature (Zhao & Peng, 2014). Preserving remaining large, road-free areas is an urgent task in today's world, especially in developing countries (Selva *et al*., 2015). For the countries where roads are rapidly expanding, planners need to systematically evaluate whether a road is really needed; and if so, explore alternative route options before dissecting or eliminating roadless areas or increasing traffic volumes in low-traffic areas.

7.3.2 An inquiry into modern models of development

> *Underlying this insight was a growing awareness that the progressive, secular, materialist philosophy on which modern life rests, indeed on which Western civilization has rested for the past three hundred years, is deeply flawed and ultimately destructive to ourselves and the whole fabric of life on the planet. The only true, sure way to the environmental goal, therefore, was to challenge that philosophy*

[24] According to the Wilderness Act of 1964 in United States, roadless areas that are larger than 2024 ha are extremely ecologically important. These areas should be protected from permanent improvements or human habitation (Selva et al., 2015).

fundamentally and find a new one based on material simplicity and spiritual richness.

Donald Worster (2014, cited in Sessions, p.108)

A new paradigm is suggested in reducing WVCs, but individual problem solving does not work well unless a major worldview is challenged. We need to see the big picture. The modernist worldview that arose in the 17^{th} and 18^{th} centuries was dominated by economics and endless growth. The root cause of the conflict between humans and nature is in the anthropocentric value system. Nature, in the modernist anthropocentrism, is only a warehouse of resources, which should be developed to satisfy the ever-increasing numbers of humans and their ever-increasing demands (Devall, 1980). “Modernity can be characterized as the era guided by an ecological theory of nature’s inexhaustibility at the broad scale, and certainly for those processes necessary to sustain overall human expectations” (Byrne *et al.*, 2002, p. 261). It occurs at the expense of other species and the integrity of the ecosystem. The anthropocentric ideology not only makes humans usurpers but advances this way of life as our right (Butler, 2014). Wilderness and biodiversity protection goals must be curtailed and clearly tied to human interests in order to be accessible (John, 2014). Human beings and the natural world are on an unsustainable collision course (World scientists’ warning to humanity, 2017). This development pattern is disastrous not only for most non-human life forms but also potentially for the human race itself. Our entire system of orientation to nature must undergo a revolution (Ehrlich, 1991).

Our authorized development is simplified to be a material growth. This development pattern is projecting the American model of society onto the rest of the world. In this model, great production is seen as the key to prosperity. Developing countries are encouraged to follow the same path. Tradition, hierarchies, mental habits—the texture of societies—have been dissolved in mechanistic models.

Political ecology does not see development as solutions, but as the primary sources of ecological problems (Byrne *et al.*, 2006). The development idea incorporates and irrevocably modifies parts of the human biological heritage for commercial ends, and it has caused serious social injustice and environmental problems (Sachs, 2009). The modern development pattern should face inquiry before it is introduced to developing countries. We should realize that the world is a collection of homogeneous entities. Developing countries should respect their traditional life styles, their deep structures of perception, and their relationships with nature. A global system of mechanism and production will result in a simplification of the biosphere and expanding environmental crisis (Sachs, 2009).

Techno-optimism is a deeply flawed worldview—not only morally and ethically but also technologically (Ehrenfeld, 2014), and mitigation or restoration never justifies what we have done. We need a new way of thinking about the natural world and our relationship with it. The development pattern should be transformed from a growth-oriented exploitative system to an "ecologically-sensitive harmony-oriented wild-minded scientific-spiritual culture" (Synder, 2016). Especially in developing countries, people and governments face a big challenge of meeting basic living standards, and it can be very hard for environmental conservation to get adequate attention. In this scenario, the local political authority should play a leading role in environmental conservation. For example, in China's history, wildlife has been viewed as an important source of food, medicine and income. This attitude towards wildlife has changed significantly in recent years. According to a survey conducted in five cities in China in 2008, 52.6% of people think wild animals are equal to human beings and both deserve protection and respect (Zhang *et al*., 2008). It is important for government authorities to adopt measures to promote this wildlife conservation awareness in public and not simply assume that the paramount goal is economic betterment at any cost.

The fundamental ecological picture needs to be drawn by a great unraveling of wild nature and indigenous human communities. Real sustainable development is done without causing the extinction of others, and by allowing other life to flourish.

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